SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

VOLUME
3

ISSUE
2

April 2024

EDITED & PUBLISHED BY

ARD
ASOCIACIÓN ESPAÑOLA

ASOCIACIÓN ESPAÑOLA DE ANÁLISIS DEL RENDIMIENTO DEPORTIVO

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Ergogenic effects of the combination of caffeine and New Zealand blackcurrant supplements on time trial: A double-blind single-case experimental study

Sebastian Zart ✉ . *Department of Sports Science. University of Kaiserslautern-Landau (RPTU). Kaiserslautern, Germany.*
Carlo Dindorf. *Department of Sports Science. University of Kaiserslautern-Landau (RPTU). Kaiserslautern, Germany.*
Michael Fröhlich. *Department of Sports Science. University of Kaiserslautern-Landau (RPTU). Kaiserslautern, Germany.*

ABSTRACT

The use of single supplements to enhance performance is widespread among athletes. The aim of this study was to increase knowledge about the combined effects of caffeine and New Zealand blackcurrant (NZBC) dietary supplements. In this counterbalanced alternating treatment single-case design, two participants each underwent four phases of four sessions in a double-blind, randomized order. After a 3-week pre-test phase, the supplement combinations of placebo/placebo, caffeine/placebo (5 mg/kg), NZBC/placebo (600 mg), and caffeine/NZBC (5 mg/kg + 600 mg) were taken and weekly performance tests were conducted to examine their effects on relative power (W/kg) during a 20-minute time trial on a bicycle. Data were analyzed descriptively and using the Tau-U calculator from Single Case Research. The ergogenic effect of caffeine was confirmed in both participants, with increases of 3.3% and 6.5%, while the positive effect of NZBC on performance was only seen in one participant (13.4%). The combination of caffeine and NZBC again increased performance in both participants (2.2% and 19.2%), but the data only showed a near additive effect of the supplements in one participant. The participants did not show a consistent performance improvement with the combined intake of the supplements caffeine and NZBC. Further studies are required to confirm or refute this evidence of the synergistic effects of these supplements.

Keywords: Sport medicine, Sport nutrition, Ergogenic aid, Endurance, Time trial, Caffeine, New Zealand blackcurrant.

Cite this article as:
Zart, S., Dindorf, C., & Fröhlich, M. (2024). Ergogenic effects of the combination of caffeine and New Zealand blackcurrant supplements on time trial: A double-blind single-case experimental study. *Scientific Journal of Sport and Performance*, *3*(2), 145-159. https://doi.org/10.55860/ENNP5024

✉ **Corresponding author.** *Department of Sports Science. University of Kaiserslautern-Landau (RPTU). Kaiserslautern, Germany.*
E-mail: zart@rptu.de

Submitted for publication November 21, 2023.
Accepted for publication December 12, 2023.
Published January 04, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/ENNP5024

INTRODUCTION

Supplements with supposed performance-enhancing effects are widely used by athletes; however, only a few have been shown to have clear effects on athletic performance (Castell, Stear, & Burke, 2015). Two very prominent supplements are caffeine (Grgic, Grgic, et al., 2020) and New Zealand blackcurrant (Braakhuis, Somerville, & Hurst, 2020). However, to the best knowledge of the authors possible interaction effects of these supplements have not been analysed so far.

Caffeine is studied in numerous endurance- and strength-based sports and tests. An umbrella review showed that it had ergogenic effects on, among other things, aerobic endurance (Cohen's d = 0.22-0.61) and muscle endurance (d = 0.28-0.38) (Grgic, Grgic, et al., 2020). With regard to the present study, a time-dependent effect on aerobic endurance with Cohen's d of 0.25 can be expected (Shen, Brooks, Cincotta, & Manjourides, 2019). Caffeine can have a positive effect on athletic performance by reducing the signs of fatigue through inhibition of adenosine binding in the central nervous system and increasing the rate of muscle contraction (Davis et al., 2003; Shen et al., 2019) when a dose of at least 3 mg/kg body weight is ingested between 30 and 90 min before exercise (Southward, Rutherfurd-Markwick, & Ali, 2018).

New Zealand blackcurrant (NZBC) contains a large amount of polyphenols, specifically anthocyanins, which have been shown to have a small but significant standardized mean percent effect of 0.45 on cycling or running performance (Braakhuis et al., 2020). One study found that cycling performance improved when a dose of 300-600 g NZBC extract (containing 105-210 mg anthocyanins) was taken before exercise for seven days (Cook, Myers, Blacker, & Willems, 2015). This increase in performance could be explained by improved blood flow (Cook, Myers, Gault, & Willems, 2017) and reduced oxidative stress (Currie et al., 2022) as anthocyanins increase nitric oxide in endothelial cells and reduce the degradation of nitric oxide by free radicals (Edirisinghe, Banaszewski, Cappozzo, McCarthy, & Burton-Freeman, 2011).

Consequently, synergistic effects could occur when these two supplements are combined. Caffeine helps physical fatigue to occur more slowly because it blocks the adenosine receptors in the body (Cormano, Redondo, Rogel, & Bach-Faig, 2020). At the same time, with the release of free fatty acids (Gutiérrez-Hellín et al., 2023) and increased blood flow (Cook et al., 2017), the combination of caffeine and NZBC could result in lower anaerobic glycolysis activity and consequently lower lactate levels due to the improved supply to working muscles. The extent to which the combination of caffeine and NZBC supplements can lead to improved performance compared to using the supplements in isolation has only been investigated in one study (Paton, Morton, Bomal, & Braakhuis, 2022). Those findings showed that cycling performance over 8 x 5-minute maximal intensity intervals showed no significant differences in the variables of power output, heart rate, oxygen consumption, muscle oxygen saturation, and rating of perceived exertion between the placebo and supplement conditions (all $p > .05$). Since the primary aim of the study was to investigate the effects of acute NZBC supplementation (Paton et al., 2022), but so far only ergogenic effects have been reported with chronic supplementation over seven days, the answer about synergistic effects of both supplements remains open. Therefore, the purpose of this study was to extend the previous findings on the combined effects of these two supplements using a chronic supplementation protocol for NZBC.

METHODS

Participants

The study included two males who were recruited via personal contact. The inclusion criteria were unrestricted resilience (no complaints of the musculoskeletal system and the cardiovascular-respiratory system) and sufficient experience in cycling.

 © 2024 ARD Asociación Española

The anthropometric data of the participants are presented in Table 1. Participant A is a mountain biker who regularly competes and can be classified as a competitive cyclist. Participant B is a recreational athlete who regularly participates in bike tours and uses a bike in everyday life but does not compete in competitions.

The study was conducted according to the Declaration of Helsinki (World Medical Association, 2013) and the combination of supplements was approved by the Ethics Committee of the RPTU Kaiserslautern-Landau (2020/55) on 20.05.2020.

Table 1. The anthropometric characteristics of the participants A and B.

Variable	**A**	**B**
Sex	m	m
Age (years)	25	32
Body height (cm)	181.5	187
Body weight (kg; Mean ± SD)	77.5 ± 0.8	90.5 ± 3.3
Skeletal muscle mass (kg; Mean ± SD)	38.8 ± 0.6	45.1 ± 1.1
Leg lean mass (kg; Mean ± SD)	20.5 ± 0.2	24.3 ± 0.6
Body Fat (%; Mean ± SD)	12.2 ± 0.5	13.0 ± 3.0
Assessment category for PWC-Power at the beginning (W/kg)[1]	+	+
Assessment category for PWC-Power at the end (W/kg)[1]	++	+++

[1] *Classification of the PWC_{150} performance into the assessment categories -, Ø, +, ++, +++ (Ferger & Büsch, 2018).*

Design

An alternating-treatment single-case design was selected to demonstrate the effects of the interventions due to its methodological advantages, since the tests at the group intervention level caused high equipment, financial, and time requirements. In addition, there was the difficulty of acquiring participants for a group intervention, as the study significantly interfered with normal training practice. Furthermore, a single-case design seemed methodologically advantageous because high intraindividual differences in the effects of caffeine supplementation have been reported, which could be accounted for by using this design (Pickering & Kiely, 2018). The study began with an initial pre-test phase of three sessions in January. Subsequently, the participants each underwent four cycles of four phases until May (participant B) respectively July (participant A):

- Baseline phase (BL), during which the participants ingested placebo caffeine and NZBC capsules;
- Caffeine phase (CAF), during which the participants took caffeine capsules and placebo NZBC capsules;
- New Zealand blackcurrant phase (NZBC), during which the participants ingested NZBC capsules and placebo caffeine capsules;
- Caffeine und NZBC phase (ALL), during which the participants ingested caffeine and NZBC capsules.

The order of the phases within the cycles was counterbalanced. Each phase lasted one week and contained one session. The measurements in each of the approximately 90-minute sessions were 7 days apart. The sessions took place on the same day at the same time for both participants. The order of the phases for each participant was determined in advance of the study (Table 2).

Due to breaks caused by illness, it was not possible for both participants to complete the phases as planned. Therefore, the measurements were resumed after the subjects' self-assessment and the measurement phase was extended in order to compensate missed sessions after the last measurement. Consequently, the counterbalanced test protocol could not be fully realized.

Interventions

The caffeine supplementation was achieved using capsules (Fitmart GmbH & Co. KG, Elmshorn, Germany), which was adjusted to a dose of 5 mg/kg body weight. The caffeine placebo consisted of equal amounts of microcrystalline cellulose. The caffeine and placebo capsules were taken 1 hour before each session on the day of the test (Southward et al., 2018).

Table 2. The sequence of the different phases.

Week	Planned phase
1	Pre-test (no supplementation)
2	Pre-test (no supplementation)
3	Pre-test (no supplementation)
4	Caffeine (CAF)
5	Caffeine + New Zealand Blackcurrant (ALL)
6	New Zealand Blackcurrant (NZBC)
7	Placebo (BL)
8	Caffeine + New Zealand Blackcurrant (ALL)
9	New Zealand Blackcurrant (NZBC)
10	Caffeine (CAF)
11	Placebo (BL)
12	New Zealand Blackcurrant (NZBC)
13	Caffeine (CAF)
14	Caffeine + New Zealand Blackcurrant (ALL)
15	Placebo (BL)
16	Caffeine (CAF)
17	Caffeine + New Zealand Blackcurrant (ALL)
18	New Zealand Blackcurrant (NZBC)
19	Placebo (BL)

The NZBC supplementation was also achieved using capsules (CurraNZ®, Health Currancy Ltd, Camberly, Great Britain), which contained 300 mg of NZBC extract. The manufacturer (CurraNZ®) also supplied the microcrystalline cellulose placebo capsules, which were identical in appearance and quantity. The participants took two capsules each for 7 days. Prior to the test days, the capsules were taken at breakfast and on the test days, they were taken 2 hours prior to the tests (Cook et al., 2015).

Depending on the phase, the supplement and placebo capsules were combined so that the same number of capsules were taken in each phase. The supplement capsules were prepared in advance of the study by an independent person who was not involved in the measurements. The participant-specific doses for each week were packed into bags so that the study could be conducted in a double-blind manner. The investigators received the labelled bags and passed them on to the participants according to the current test week.

Procedure

Before each test, the participants were instructed to have an identical breakfast, not to consume caffeinated foods or beverages for 48 hours, not to consume alcohol or polyphenol-rich foods or beverages for 24 hours, and not to perform intensive exercise for 24 hours. The endurance tests were performed using a Cyclus2® ergometer (RBM elektronik-automation GmbH, Leipzig, Germany) so that both participants could complete all tests on their own road bike with their own individual settings. Before the start of the study, the participants' positions on their bikes were checked according to common practice (Bartaguiz, Dindorf, Dully, Becker, & Fröhlich, 2022).

On the first day of testing, height and weight of the participants were measured and a bioimpedance analysis (BIA) was performed to determine their body compositions. The BIA was repeated regularly over the data collection period.

 © 2024 ARD Asociación Española

At the beginning of each testing session, the participants' resting blood pressure and heart rate were measured. After this, the participants completed the Short Recovery and Stress Scale for Sports (SRSS) questionnaire (Kellmann & Kölling, 2019) and the physical work capacity 150 (PWC_{150}) test to warm up and check their current aerobic performance capacity. During the test, the participants' heart rates were measured. The participants were allowed to select an individual cadence for the first measurement, which was then fixed for all subsequent measurements. At the end of the PWC_{150}, the rating of perceived exertion (RPE) was determined by the participants. The PWC_{150} was followed by a 10-minute recovery period at 100 W, which was also at a self-selected cadence. During the last 2 minutes of recovery, a portable metabolic system was attached to the participants and coupled with the Cyclus2® ergometer. Subsequently, the participants completed a 20-minute time trial (TT), during which the highest possible power output was to be achieved over time. The participants were allowed to select their wattage and cadence independently (Sitko, Cirer-Sastre, Corbi, & López-Laval, 2020). The power-related data were not blinded.

Measures

During the study body weight (kg), proportional skeletal muscle mass (kg), fat mass percentage (%), the ratio of extracellular to total body water, and lean leg mass (kg) were measured using a BIA (InBody770, InBody Europe, Eschborn, Germany). Resting systolic (sBP; mmHg), diastolic blood pressure (dBP; mmHg) and resting heart rate (rHR; bpm) were measured three times after 10 minutes of rest in the supine position on a yoga mat (Tensoval® comfort, Paul Hartmann AG, Heidenheim, Germany; Polar H10, Polar Electro Oy, Kempele, Finland) and then the mean value was calculated. The athletes' recovery and stress status were measured using the SRSS with Cronbach's α = 0.78-0.84 (Kellmann & Kölling, 2019). During the PWC_{150}, which has a reliability of r = 0.78 (McArdle, Katch, Pechar, Jacobson, & Ruck, 1972), the relative power (PWC-Power; W/kg) was measured, starting with a power of 100 W and increasing by 25 W every 2 minutes. After the PWC_{150}, the participants' exertion (RPE_{150}) was determined using a valid Borg scale ($r \approx 0.6$) (Chen, Fan, & Moe, 2002). For spiroergometric measurement during TTs, the K5 device (COSMED® S.r.l., Rome, Italy) with breath-by-breath method was used, which reproduces data with less than 2% deviation (Winkert, Kamnig, Kirsten, Steinacker, & Treff, 2020). Studies have also confirmed the reproducibility of power output in 20-minute TTs (r = 0.98) (Nimmerichter, Williams, Bachl, & Eston, 2010). Relative power normalized by weight (primary outcome variable) for better comparability (TT-Power; W/kg) and the variables RPE, average (HR_{mean}; bpm) and maximum (HR_{max}; bpm) heart rate, respiratory exchange ratio (RER), oxygen volume (VO_2; ml), and carbon dioxide volume (VCO_2; ml) were measured at minutes 5, 10, 15, and 20 as secondary outcomes.

Analysis

All data were graphed for each participant using Excel 2019 (Microsoft, Redmond, WA, USA) and each phase was visually analysed (Kratochwill et al., 2013). In the visual inspections, we examined changes within and between phases to identify trends, changes in level or stability (criterion fulfilled when 85% of the data in a phase fall within a 15% range of the median of all data points for that phase), and overlaps between the BL and CAF, NZBC, or ALL phases (Lobo, Moeyaert, Baraldi Cunha, & Babik, 2017). To facilitate this visual analysis, a line was mapped for the median values of all sessions within each phase. The Tau-U calculator from Single Case Research (http://singlecaseresearch.org/calculators/tau-u) was used to determine the trends within each phase, any contrasts between the phases, and the combined analysis of both participants.

RESULTS

Recovery and Stress perception

The weekly questionnaire on the recovery and stress states of the participants only showed small variations between the phases (Figure 1) and the calculated contrasts showed no significant differences (all *p* > .05). Consequently, it was assumed that the physical conditions were the same on all measurement days.

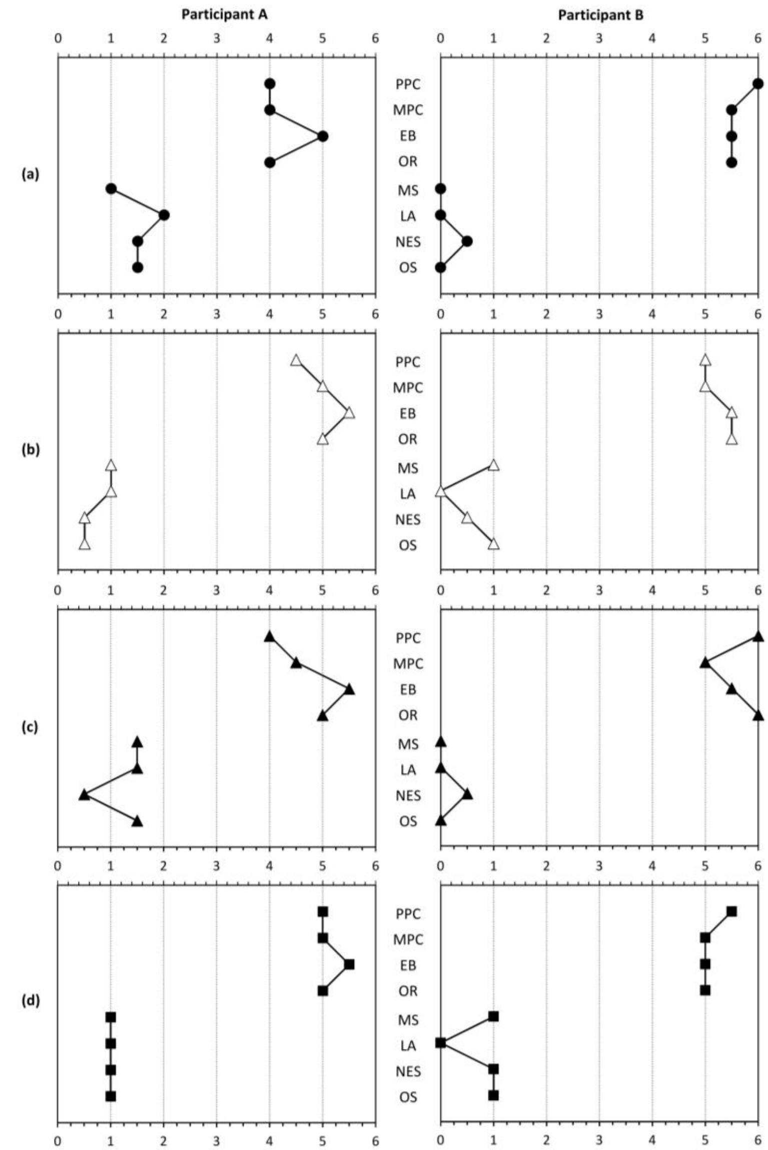


Figure 1. The median results of the Short Recovery and Stress Scale for Sports with the two dimensions Recovery (PPC, physical performance capability; MPC, mental performance capability; EB, emotional balance; OR, overall recovery) and Stress (MS, muscular stress; LA, lack of activation; NES, negative emotional state; OS, overall stress) for subjects A and B across the four phases: (a) baseline phase; (b) caffeine phase; (c) New Zealand blackcurrant phase; (d) caffeine + New Zealand blackcurrant phase.

Physiological and performance parameters

Stability

The characteristics of the participants in the BL phase were considered stable at 75-100% (Tables 3 and 5). Only the rHR variable for participant B showed a lower stability of 50%.

In the treatment phases, participant A showed the same stability across all variables, with only the rHR variable showing lower stability (50%) in the CAF and ALL phases (Table 3). For participant B, the lowest stability was observed at 50% for sBP (CAF), rHR (NZBC), and PWC-power (CAF, NZBC). However, as in the BL phase, there was an overall high stability of at least 75% (Table 5).

© 2024 ARD Asociación Española

Table 3. The median results of the resting values, the physical working capacity test, and the time trial for participant A.

Level	BL	CAF	NZBC	ALL
		Resting Parameters		
sBP (mmHg)	123	128	127.33	129
dBP (mmHg)	64	74*	65.83	72*
rHR (bpm)	57	57	60	57
		Physical Working Capacity Test (PWC_{150})		
PWC-Power (W/kg)	2.91	2.87	2.96	2.82*
RPE_{150}	16	14.5	15	14.50*
		Time Trial (TT)		
TT-Power (W/kg)	3.57	3.72*	3.51	3.68
HR_{mean} (bpm)	168	176*	168	175*
HR_{max} (bpm)	178	186*	180	187*
RER	0.85	0.83	0.88	0.84
VO_2 (ml)	4995	5219	4520*	5095
VCO_2 (ml)	4172	4340	3962	4300
		RPE		
After 5 min	17	16.5	16.5	17
After 10 min	17.5	17.5	17.5	18
After 15 min	19	19	18.5	19
After 20 min	19.5	20	20	20
Stability	**BL (%)**	**CAF (%)**	**NZBC (%)**	**ALL (%)**
		Resting Parameters		
sBP	100	100	100	100
dBP	75	100	75	100
rHR	75	50	75	50
		Physical Working Capacity Test (PWC_{150})		
PWC-Power	100	100	75	75
RPE_{150}	100	75	100	100
		Time Trial (TT)		
TT-Power	100	100	100	75
HR_{mean}	100	100	100	100
HR_{max}	100	100	100	100
RER	100	75	100	100
VO_2	100	75	75	75
VCO_2	100	100	100	100
		RPE		
After 5 min	100	100	100	100
After 10 min	75	100	100	100
After 15 min	100	100	100	100
After 20 min	100	100	100	100

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); RER (respiratory exchange ratio); rHR (resting heart rate); RPE (rate of perceived exertion); sBP (systolic blood pressure); VCO_2 (carbon dioxide volume); VO_2 (oxygen volume); *significant difference to BL phase, $p < .05$.*

Table 4. Results on the contrasts from the non-parametric method Tau-U between the phases for participant A.

Variable	BL vs. CAF	BL vs. NZBC	BL vs. ALL
	(TAU-U; *p*-value)	(TAU-U; *p*-value)	(TAU-U; *p*-value)
dBP (mmHg)	0.875; .043		1.000; .021
PWC-Power (W/kg)			-0.875; .043
RPE_{150}			-0.875; .043
TT-Power (W/kg)	1.000; .021		
HR_{mean} (bpm)	1.000; .021		0.875; .043
HR_{max} (bpm)	1.000; .021		1.000; .021
VO_2 (ml)		-1.000; .021	

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); PWC (physical working capacity); RPE (rate of perceived exertion); TT (time trial); VO_2 (oxygen volume); *significant difference to BL phase, $p < .05$.*

Table 5. The median results of the resting values, the physical working capacity test, and the time trial for participant B.

Level	BL	CAF	NZBC	ALL
Resting Parameters				
sBP (mmHg)	120	129	121	130*
dBP (mmHg)	72	74	73	75*
rHR (bpm)	48	43	49	44
Physical Working Capacity Test (PWC_{150})				
PWC-Power (W/kg)	3.36	3.26	3.25	3.26
RPE_{150}	19	17.5	18	18
Time Trial (TT)				
TT-Power (W/kg)	2.76	2.94*	3.13*	3.29*
HR_{mean} (bpm)	160	165*	161	165*
HR_{max} (bpm)	171	176*	172	177*
RER	0.91	0.83	0.92	0.85
VO_2 (ml)	4486	4834	4581	4791
VCO_2 (ml)	3966	4076	3949	4036
RPE				
After 5 min	16	16	15	16
After 10 min	17.5	17.5	17	17.5
After 15 min	18.5	19	18	18.5
After 20 min	20	20	20	20
Stability	**BL (%)**	**CAF (%)**	**NZBC (%)**	**ALL (%)**
Resting Parameters				
sBP	100	50	100	100
dBP	100	75	100	100
rHR	50	75	50	75
Physical Working Capacity Test (PWC_{150})				
PWC-Power	75	50	50	75
RPE_{150}	100	75	75	100
Time Trial (TT)				
TT-Power	100	100	100	100
HR_{mean}	100	100	100	100
HR_{max}	100	100	100	100
RER	100	100	75	100
VO_2	100	100	100	100
VCO_2	100	100	75	100
RPE				
After 5 min	100	100	75	100
After 10 min	100	100	100	75
After 15 min	100	100	100	100
After 20 min	100	100	100	100

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); RER (respiratory exchange ratio); rHR (resting heart rate); RPE (rate of perceived exertion); sBP (systolic blood pressure); VCO_2 (carbon dioxide volume); VO_2 (oxygen volume); *significant difference to BL phase, $p < .05$.*

Table 6. Results on the contrasts from the non-parametric method Tau-U between the phases for participant B.

Variable	BL vs. CAF	BL vs. NZBC	BL vs. ALL
	(TAU-U; *p*-value)	(TAU-U; *p*-value)	(TAU-U; *p*-value)
dBP (mmHg)			1.000; .021
sBP (mmHg)			1.000; .021
TT-Power (W/kg)	1.000; .021	1.000; .021	1.000; .021
HR_{mean} (bpm)	1.000; .034		0.875; .043
HR_{max} (bpm)	1.000; .034		1.000; .021

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); sBP (systolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); TT (time trial); *significant difference to BL phase, $p < .05$.*

© 2024 ARD Asociación Española

Trends

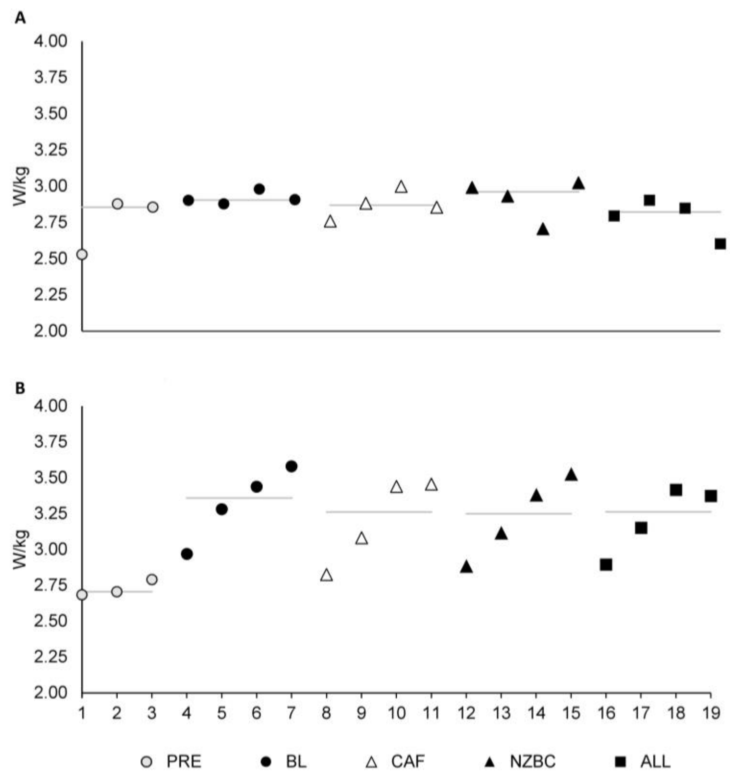
The trend analysis for the variables of participant A revealed a significant result for the rHR variable (TAU-U = -1.000; p = .042) in the CAF phase. The participant's resting heart rate decreased steadily over the four sequences.

For participant B, there were significant trends for the PWC-Power variable in the BL (TAU-U = 1.000; p = .042), CAF (TAU-U = 1.000; p = .042), and NZBC (TAU-U = 1.000; p = .042) phases. In general, there was a significant increase in PWC_{150} performance in all phases throughout the study period. Additionally, increasing trends were observed for the VCO_2 variable in the BL phase (TAU-U = 1.000; p = .042), the TT-Power variable in the NZBC phase (TAU-U = 1.000; p = .042), and the rHR variable in the ALL phase (TAU-U = 1.000; p = .042).

Levels

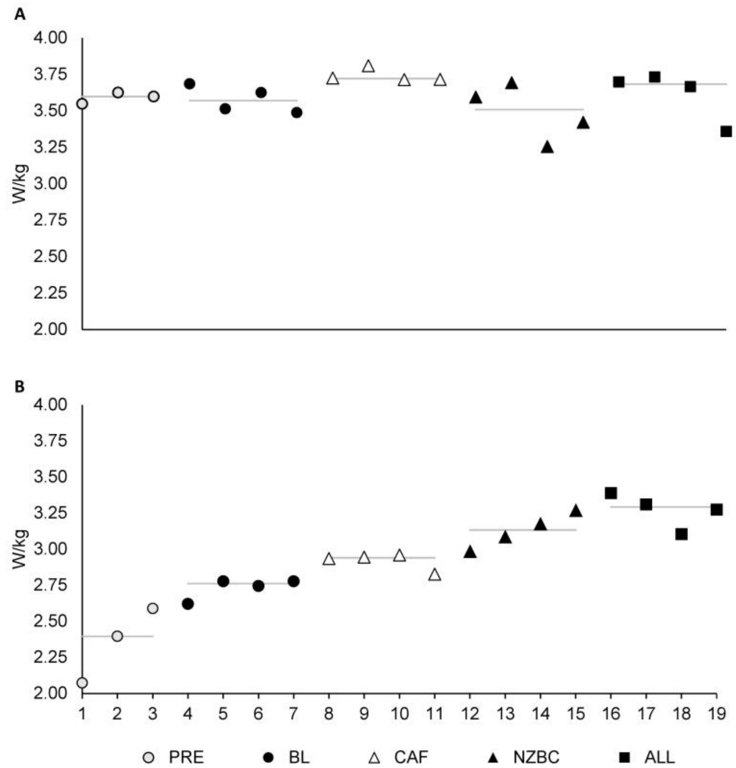
Results for each phase are shown for participant A in Table 3, Table 4, Figure 2a, and Figure 3a, and for participant B in Table 5, Table 6, Figure 2b, and Figure 3b. Only the combined results on significant contrasts from the nonparametric method Tau-U across both participants are reported below.

Most contrasts occurred between the BL and CAF phases, with significant differences observed in the RPE_{150} (TAU-U = -0.656; p = .032), TT-Power (TAU-U = 1.000; p = .011), HR_{mean} (TAU-U = 1.000; p = .002), HR_{max} (TAU-U = 1.000; p = .002), and VO_2 (TAU-U = 0.750; p = .014) variables. In addition, significant differences also occurred in the sBP (TAU-U = 0.844; p = .006), dBP (TAU-U = 1.000; p = .001), PWC-Power (TAU-U = -0.813; p = .008), RPE_{150} (TAU-U = -0.844; p = .006), TT-Power (TAU-U = 0. 688; p = .025), HR_{mean} (TAU-U = 0.875; p < .004), HR_{max} (TAU-U = 1.000; p = .001), and VO_2 (TAU-U = -0.625; p = .041) variables between the BL and ALL phases. Only the RPE_{150} value (TAU-U = -0.656; p = .032) differed between the BL and NZBC phases.



ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); NZBC (New Zealand blackcurrant phase); PRE (pre-test phase (without supplementation)); The horizontal lines show the median values for each phase.

Figure 2. The performance relative to the weight of each participant (A, B) during the PWC_{150} in the five phases.



ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); NZBC (New Zealand blackcurrant phase); PRE (pre-test phase (without supplementation)); The horizontal lines show the median values for each phase.

Figure 3. The performance relative to the weight of each participant (A, B) during the time trials in the five phases.

DISCUSSION

This explorative study tested the combined effects of caffeine and New Zealand blackcurrant supplements during maximal endurance exercise on a bike over 20 minutes. The results showed that the maximum performance of both participants developed inconsistently over the treatment phases.

During the TT, the cycling performance of participant A only increased when supplementary caffeine was taken (CAF: +3.3%; ALL: +2.2%). The performance increases were on the same levels as those reported in other studies (Doherty & Smith, 2004; Southward et al., 2018). The performance in the CAF phase was even significantly increased compared to that in the BL phase. Thus, in contrast to the results from a study by Paton et al. (2022), participant A was able to improve performance in a treatment phase compared to the BL phase. However, it should be mentioned in this comparison that in a cohort study the group means could be influenced by some non-responders. Participant A showed a lower performance in the NZBC phase. Of course, this could have been related to participant A suffering from a mild case of COVID-19. A total of four sessions were performed after participant A had recovered from COVID-19 and measurements 7, 14, 15, and 19 were affected (Table 2). In each of these four tests, participant A performed lower compared to the other tests in the phases. Due to the fact that 50% of the measurements in phase NZBC were affected by participant A's illness, the median across all data points (3.51 W/kg) probably did not reflect the actual performance of participant A (the MD of the two performances before disease: 3.65 W/kg). A study by Śliż et al. (2022) indicated that maximal heart rate and oxygen volume values could be less pronounced during cardiorespiratory graded tests, even long after COVID-19 infection. In participant A, this was found to be true with respect to oxygen volume when comparing the pre- (VO_2 = 4.67 L/min) and post-COVID-19 (VO_2 = 4.31 L/min) measurements in the NZBC phase.

 © 2024 ARD Asociación Española

Participant B exhibited an ergogenic effect of the supplements when taken individually and in combination. Compared to the BL phase, New Zealand blackcurrant (+13.4%) supplementation resulted in a greater increase in performance than caffeine (+6.5%) supplementation, while the combination of supplements (+19.2%) provided an additional ergogenic effect. Contrary to the reported results from other studies, participant B was able to significantly increase relative performance by using NZBC extract (Murphy, Cook, & Willems, 2017). The influence on the results of the reduction in body weight, which occurred due to the increased cycling since spring, and the increase in performance during the PWC_{150} over the course of the data collection period could be excluded due to the randomization of the phases because all phases were equally affected by these changes.

In the present study, the CYP1A2 genotype of the participants was not known; therefore, we could not draw any conclusions about their metabolism of caffeine. However, based on the results from studies that have examined the influence of this genotype on blood pressure in response to caffeine ingestion, slow metabolizers can show a significant increase in systolic blood pressure following caffeine ingestion (Soares, Schneider, Valle, & Schenkel, 2018) and the vasoconstriction of vessels can result in decreased blood flow to the heart and other muscles (Guest, Corey, Vescovi, & El-Sohemy, 2018). According to a review by Higgins and Babu (2013), an acute increase of 5-10% in resting systolic and diastolic blood pressure occurred after caffeine ingestion and myocardial blood flow was reduced by up to 22% during exercise. Looking at the blood pressure values of the two participants, it was noted that both participants showed increases in systolic blood pressure (participant A: 4-5%; participant B: 7-9%). Based on the results of Guest et al. (2018), it could be concluded that the performance of participant A corresponds to a slow metabolizer of genotype AC, who also achieved a performance increase of approximately 3 % with a caffeine dose of 4 g/kg. Participant B, on the other hand, showed an increase in performance consistent with genotype AA (fast metabolizer), which was not consistent with the increased blood pressure values (Guest et al., 2018).

The participants showed significant increases in their mean and maximum heart rates in the CAF and ALL phases compared to those in the BL phase (Irwin et al., 2011; Smirmaul, de Moraes, Angius, & Marcora, 2017), which could indicate stronger exertion and explain the increased performance during the TT. However, it should be mentioned that some studies have found no changes in heart rate due to caffeine, despite increased performance (Anderson, German, Harrison, Bourassa, & Taylor, 2020; Grgic, Diaz-Lara, et al., 2020). In contrast, the heart rate parameters of the participants hardly changed in the NZBC phase: participant A showed comparable values with lower power output and participant B showed significantly increased power output with similar average and maximum heart rates. The effect of New Zealand blackcurrant ingestion on heart rate has not been substantiated by other studies, so natural variations were assumed in both cases. The increase in performance could have been caused by improved blood flow to the working muscles (Cook et al., 2017), although this could not be supported by the available data.

According to a meta-analysis by Conger, Tuthill, and Millard-Stafford (2023), caffeine significantly promoted fat metabolism that was operationalized by RER (ES = 0.19). Compared to the BL phase, the RER values of both participants decreased in the CAF and ALL phases and thus, could indicate increased fat metabolism. This effect could not be measured by the RER parameter in the NZBC phase, although the anthocyanins contained in New Zealand blackcurrant extract have been shown to increase fat oxidation (Cook et al., 2015; Strauss, Willems, & Shepherd, 2018). In a study by Cook et al. (2015), the respiratory quotient did not change despite increased fat oxidation, so this variable may not adequately reflect fat oxidation.

The reduction in perceived exertion due to caffeine ingestion during TT could not be measured using the RPE parameter, although some studies have partly shown the effect of caffeine on self-perceived fatigue (Ruiz-Moreno et al., 2021). Similarly, RPE remained at the same level when NZBC was ingested. Thus, our results were similar to those from other studies that have also documented no changes in perceived exertion (Backhouse, Biddle, Bishop, & Williams, 2011; Godwin, Cook, & Willems, 2017).

Regarding data quality, for all measurements, the time sequences on the test days were standardized and implemented without changes. The participants always used their own bikes with their individually optimized settings and were able to replicate their performance under similar conditions. The chosen systematic randomized design also compensated for changes in physical conditions, so all conditions were equally affected by developmental effects. In accordance with single-case study guidelines, the present study was able to measure sufficient data points in each phase to allow for the testing of the effects of the supplements (Kratochwill et al., 2013).

Of course, the long study period of half a year caused some potential problems. The participants had to motivate themselves every week to produce their maximum performance. This was certainly difficult, especially after the periods of illness. Participant A had a cold in test weeks 12 and 14 and COVID-19 in test week 18. Participant B exhibited more severe cold symptoms in test week 15 and was physically unable to participate in the session. Consequently, the pre-established session order could not be followed for either participant. Thus, the measurements were resumed after self-assessment by the participants and the data collection phase was extended accordingly. In addition, it was not possible to check whether the capsules were taken correctly after the supplements were issued, despite regular notifications. Another limitation is the different performance level of the participants. The extent to which the level of aerobic capacity has influenced the effects of the supplements cannot be clarified based on the present studies results due to the small number of participants as well as the single-case design.

CONCLUSION

Based on this study, only the ergogenic effects of caffeine could be confirmed across both participants. Consequently, caffeine intake of 5 mg/kg body weight increased endurance performance during a time trial of 20 minutes. Only participant B indicated that both supplements could have synergistic effects. Further research in this area is needed to strengthen or weaken this indication.

AUTHOR CONTRIBUTIONS

SZ, CD and MF designed the study, with SZ and CD collecting the data. SZ conducted data analysis and interpretation, drafted the manuscript, and received critical revisions from MF and CD. All authors contributed to the article and approved the submitted version.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ACKNOWLEDGMENTS

The authors would like to express their sincere thanks to Pia Melzer and Jonas Gruhn, students of the Bachelor of Science program and members of the project team, for their support in collecting and processing the data. The authors would also like to thank all study participants for their participation.

© 2024 ARD Asociación Española

REFERENCES

Anderson, D. E., German, R. E., Harrison, M. E., Bourassa, K. N., & Taylor, C. E. (2020). Real and Perceived Effects of Caffeine on Sprint Cycling in Experienced Cyclists. J Strength Cond Res, 34(4), 929-933. https://doi.org/10.1519/JSC.0000000000003537

Backhouse, S. H., Biddle, S. J., Bishop, N. C., & Williams, C. (2011). Caffeine ingestion, affect and perceived exertion during prolonged cycling. Appetite, 57(1), 247-252. https://doi.org/10.1016/j.appet.2011.05.304

Bartaguiz, E., Dindorf, C., Dully, J., Becker, S., & Fröhlich, M. (2022). Effects of increasing physical load and fatigue on the biomechanics of elite cyclists. Scientific Journal of Sport and Performance, 2(1), 59-69. https://doi.org/10.55860/NBMD9425

Braakhuis, A. J., Somerville, V. X., & Hurst, R. D. (2020). The effect of New Zealand blackcurrant on sport performance and related biomarkers: a systematic review and meta-analysis. Journal of the International Society of Sports Nutrition, 17(1), 25-25. https://doi.org/10.1186/s12970-020-00354-9

Castell, L. M., Stear, S. J., & Burke, L. M. (2015). Nutritional Supplements in Sport, Exercise and Health: An A-Z Guide. Abingdon: Routledge. https://doi.org/10.4324/9781315772509

Chen, M. J., Fan, X., & Moe, S. T. (2002). Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. Journal of Sports Sciences, 20(11), 873-899. https://doi.org/10.1080/026404102320761787

Conger, S. A., Tuthill, L. M., & Millard-Stafford, M. L. (2023). Does Caffeine Increase Fat Metabolism? A Systematic Review and Meta-Analysis. International Journal of Sport Nutrition and Exercise Metabolism, 33(2), 112-120. https://doi.org/10.1123/ijsnem.2022-0131

Cook, M. D., Myers, S. D., Blacker, S. D., & Willems, M. E. T. (2015). New Zealand blackcurrant extract improves cycling performance and fat oxidation in cyclists. European Journal of Applied Physiology and Occupational Physiology, 115(11), 2357-2365. https://doi.org/10.1007/s00421-015-3215-8

Cook, M. D., Myers, S. D., Gault, M. L., & Willems, M. E. T. (2017). Blackcurrant Alters Physiological Responses and Femoral Artery Diameter during Sustained Isometric Contraction. Nutrients, 9(6), 556. https://doi.org/10.3390/nu9060556

Cormano, E. B., Redondo, R. B., Rogel, M., & Bach-Faig, A. (2020). Effect of caffeine as an ergogenic aid to prevent muscle fatigue.

Currie, T. L., Engler, M. M., Olsen, C. H., Krauthamer, V., Scott, J. M., Deuster, P. A., & Flagg, T. P. (2022). The Effects of Blackcurrant and Berry Extracts on Oxidative Stress in Cultured Cardiomyocytes and Microglial Cells. The FASEB Journal, 36(S1). https://doi.org/10.1096/fasebj.2022.36.S1.R2805

Davis, J. M., Zhao, Z., Stock, H. S., Mehl, K. A., Buggy, J., & Hand, G. A. (2003). Central nervous system effects of caffeine and adenosine on fatigue. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 284(2), R399-R404. https://doi.org/10.1152/ajpregu.00386.2002

Doherty, M., & Smith, P. M. (2004). Effects of Caffeine Ingestion on Exercise Testing: A Meta-Analysis. 14(6), 626. https://doi.org/10.1123/ijsnem.14.6.626

Edirisinghe, I., Banaszewski, K., Cappozzo, J., McCarthy, D., & Burton-Freeman, B. M. (2011). Effect of Black Currant Anthocyanins on the Activation of Endothelial Nitric Oxide Synthase (eNOS) in Vitro in Human Endothelial Cells. Journal of Agricultural and Food Chemistry, 59(16), 8616-8624. https://doi.org/10.1021/jf201116y

Godwin, C., Cook, M. D., & Willems, M. E. T. (2017). Effect of New Zealand Blackcurrant Extract on Performance during the Running Based Anaerobic Sprint Test in Trained Youth and Recreationally Active Male Football Players. Sports, 5(3), 69. https://doi.org/10.3390/sports5030069

Grgic, J., Diaz-Lara, F. J., Coso, J. D., Duncan, M. J., Tallis, J., Pickering, C., . . . Mikulic, P. (2020). The Effects of Caffeine Ingestion on Measures of Rowing Performance: A Systematic Review and Meta-Analysis. Nutrients, 12(2). https://doi.org/10.3390/nu12020434

Grgic, J., Grgic, I., Pickering, C., Schoenfeld, B. J., Bishop, D. J., & Pedisic, Z. (2020). Wake up and smell the coffee: caffeine supplementation and exercise performance-an umbrella review of 21 published meta-analyses. British Journal of Sports Medicine, 54(11), 681-688. https://doi.org/10.1136/bjsports-2018-100278

Guest, N., Corey, P., Vescovi, J., & El-Sohemy, A. (2018). Caffeine, CYP1A2 Genotype, and Endurance Performance in Athletes. Medicine and Science in Sports and Exercise, 50(8), 1570-1578. https://doi.org/10.1249/MSS.0000000000001596

Gutiérrez-Hellín, J., Aguilar-Navarro, M., Ruiz-Moreno, C., Muñoz, A., Varillas-Delgado, D., Amaro-Gahete, F. J., & Del Coso, J. (2023). Effect of caffeine intake on fat oxidation rate during exercise: is there a dose-response effect? European Journal of Nutrition, 62(1), 311-319. https://doi.org/10.1007/s00394-022-02988-8

Higgins, J. P., & Babu, K. M. (2013). Caffeine reduces myocardial blood flow during exercise. American Journal of Medicine, 126(8), 730.e731-738. https://doi.org/10.1016/j.amjmed.2012.12.023

Irwin, C., Desbrow, B., Ellis, A., O'Keeffe, B., Grant, G., & Leveritt, M. (2011). Caffeine withdrawal and high-intensity endurance cycling performance. Journal of Sports Sciences, 29(5), 509-515. https://doi.org/10.1080/02640414.2010.541480

Kellmann, M., & Kölling, S. (2019). Recovery and Stress in Sport: A Manual for Testing and Assessment (1. ed.). London: Routledge. https://doi.org/10.4324/9780429423857

Kratochwill, T. R., Hitchcock, J. H., Horner, R. H., Levin, J. R., Odom, S. L., Rindskopf, D. M., & Shadish, W. R. (2013). Single-Case Intervention Research Design Standards. Remedial and Special Education, 34(1), 26-38. https://doi.org/10.1177/0741932512452794

Lobo, M. A., Moeyaert, M., Baraldi Cunha, A., & Babik, I. (2017). Single-Case Design, Analysis, and Quality Assessment for Intervention Research. J Neurol Phys Ther, 41(3), 187-197. https://doi.org/10.1097/NPT.0000000000000187

McArdle, W. D., Katch, F. I., Pechar, G. S., Jacobson, L., & Ruck, S. (1972). Reliability and interrelationships between maximal oxygen intake, physical work capacity and step-test scores in college women. Medicine and Science in Sports, 4(4), 182-186. https://doi.org/10.1249/00005768-197200440-00019

Murphy, C., Cook, M. D., & Willems, M. E. T. (2017). Effect of New Zealand Blackcurrant Extract on Repeated Cycling Time Trial Performance. Sports, 5(2), 25. https://doi.org/10.3390/sports5020025

Nimmerichter, A., Williams, C., Bachl, N., & Eston, R. (2010). Evaluation of a Field Test to Assess Performance in Elite Cyclists. International Journal of Sports Medicine, 31(03), 160-166. https://doi.org/10.1055/s-0029-1243222

Paton, C. D., Morton, L. C., Bomal, B., & Braakhuis, A. J. (2022). The Effects of Blackcurrant and Caffeine Combinations on Performance and Physiology During Repeated High-Intensity Cycling. Int J Sport Nutr Exerc Metab, 32(6), 462-467. https://doi.org/10.1123/ijsnem.2022-0087

Pickering, C., & Kiely, J. (2018). Are the Current Guidelines on Caffeine Use in Sport Optimal for Everyone? Inter-individual Variation in Caffeine Ergogenicity, and a Move Towards Personalised Sports Nutrition. Sports Medicine, 48(1), 7-16. https://doi.org/10.1007/s40279-017-0776-1

Ruiz-Moreno, C., Gutiérrez-Hellín, J., Amaro-Gahete, F. J., González-García, J., Giráldez-Costas, V., Pérez-García, V., & Del Coso, J. (2021). Caffeine increases whole-body fat oxidation during 1 h of cycling at Fatmax. European Journal of Nutrition, 60(4), 2077-2085. https://doi.org/10.1007/s00394-020-02393-z

Shen, J. G., Brooks, M. B., Cincotta, J., & Manjourides, J. D. (2019). Establishing a relationship between the effect of caffeine and duration of endurance athletic time trial events: A systematic review and meta-analysis. Journal of Science and Medicine in Sport, 22(2), 232-238. https://doi.org/10.1016/j.jsams.2018.07.022

Sitko, S., Cirer-Sastre, R., Corbi, F., & López-Laval, I. (2020). Power Assessment in Road Cycling: A Narrative Review. Sustainability, 12(12), 5216. https://doi.org/10.3390/su12125216

Śliż, D., Wiecha, S., Ulaszewska, K., Gąsior, J. S., Lewandowski, M., Kasiak, P. S., & Mamcarz, A. (2022). COVID-19 and athletes: Endurance sport and activity resilience study-CAESAR study. Frontiers in physiology, 13. https://doi.org/10.3389/fphys.2022.1078763

Smirmaul, B. P., de Moraes, A. C., Angius, L., & Marcora, S. M. (2017). Effects of caffeine on neuromuscular fatigue and performance during high-intensity cycling exercise in moderate hypoxia. European Journal of

 © 2024 ARD Asociación Española

Applied Physiology and Occupational Physiology, 117(1), 27-38. https://doi.org/10.1007/s00421-016-3496-6

Soares, R. N., Schneider, A., Valle, S. C., & Schenkel, P. C. (2018). The influence of CYP1A2 genotype in the blood pressure response to caffeine ingestion is affected by physical activity status and caffeine consumption level. Vascul Pharmacol, 106, 67-73. https://doi.org/10.1016/j.vph.2018.03.002

Southward, K., Rutherfurd-Markwick, K. J., & Ali, A. (2018). The Effect of Acute Caffeine Ingestion on Endurance Performance: A Systematic Review and Meta-Analysis. Sports Medicine, 48(8), 1913-1928. https://doi.org/10.1007/s40279-018-0939-8

Strauss, J. A., Willems, M. E. T., & Shepherd, S. O. (2018). New Zealand blackcurrant extract enhances fat oxidation during prolonged cycling in endurance-trained females. European Journal of Applied Physiology, 118(6), 1265-1272. https://doi.org/10.1007/s00421-018-3858-3

Winkert, K., Kamnig, R., Kirsten, J., Steinacker, J. M., & Treff, G. (2020). Inter- and intra-unit reliability of the COSMED K5: Implications for multicentric and longitudinal testing. PLOS ONE, 15(10), e0241079. https://doi.org/10.1371/journal.pone.0241079

World Medical Association. (2013). World medical association declaration of Helsinki: Ethical principles for medical research involving human subjects. Journal of the American Medical Association, 310(20), 2191-2194. https://doi.org/10.1001/jama.2013.281053

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

REVIEW ARTICLE

Resistance training status detection via local muscular endurance adaptation maximum repetition strategy: Brief review

Yeliz Kahraman . *Movement and Training Laboratory. Sport Faculty Department. Akdeniz University. Turkey.*
İsmail Varol. *Movement and Training Laboratory. Sport Faculty Department. Akdeniz University. Turkey.*

ABSTRACT

Aim: The strength-endurance maximum repetition strategy is local muscular endurance development via unprompted fatigue to voluntary contraction adaptation. Brief review aimed to maximum repetition developing on exercise selection and maximal repetition strategy of resistance training constant set workload. Multiple set and endurance maximum repetition strategy must be planned according to purposing resistance training science. Methods: The local muscular endurance periodic session and periodization detected to strength-endurance maximum repetition strategy including loading change and constant repetition set set-ups respectively, 102.3%, 90%, 85%, 80%, 75%, 70%, 65%, 60%, 55%, 50%, 45%, 40% and 30%1RM. The population of resistance training formed on local muscular endurance adaptation to date below of 2023 yr. to trained or untrained resistance individuals obtained from PubMed and Web of Science databases, specifically in S&C Journal investigation. Results: Primarily analysis of LME strategy used to absolute endurance and relative endurance performance uncommon without this critical literature search. Again, strength-endurance loading resistance session have been performed to develop absolute endurance provided high load low repetition strategy commonly used to performance detection and relative endurance detected low load high repetition strategy detected to neurofatigue detection using strength-endurance maximum repetition periodization in researches. Conclusion: Resistance training population may be detecting time-dependent strength and endurance maximum repetition periodic periodization session local muscular endurance adaptation to develop neuromuscular adaptation and strength gain. In conclusion, actual exercise and resistance training can be dependent to LME strategy.
Keywords: LME strategy, Resistance training, Absolute endurance, Relative endurance.

Cite this article as:
Kahraman, Y., & Varol, I. (2024). Resistance training status detection via local muscular endurance adaptation maximum repetition strategy: Brief review. *Scientific Journal of Sport and Performance*, *3*(2), 160-169. https://doi.org/10.55860/SWDB1533

Corresponding author. *Movement and Training Laboratory. Health Science Department. Akdeniz University. Turkey.*
E-mail: yelizkahramana@hotmail.com
Submitted for publication January 03, 2024.
Accepted for publication February 07, 2024.
Published March 01, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/SWDB1533

INTRODUCTION

One of resistance training is local muscular endurance via strength-endurance maximum repetition strategy in dynamic strength and effective speed gain to enhance neuromuscular adaptation and strength gain, however, resistance training process from past to present to local muscular endurance adaptation uncommon popular resistance training periodization.

Endurance resistance sessions are developed maximize strength based repetition maximum set-up (Bastos-Silva et al., 2019; Iglesias et al., 2010; Pryor et al., 2011). In this case, general endurance training principle has been explained gradually maximal strength loading increase and equated volume change to reach repetition maximum strategy (Cesar et al., 20099. However, local muscular endurance adaptation is linear progression to each resistance training periodization specifically to provide loading and volume increase performing single or multiple set session (Conrado de Freitas et al., 2018; Mann et al., 2015).

The currently loading intensity change or repetition increase and decrease plan show maximum repetition (Rodriguez-Rosell et al., 2020; Shimano et al., 2006). Current review approach is that resistance training periodization should be perform on strength and endurance maximum repetition strategy to determine exercise and training condition (Clarke et al., 2015; Hirsch and Frost, 2021; Terzis et al., 2008).

Maximum repetition for example local muscular endurance adaptation planned on reverse loading periodization with 5-10% intensity change to provide absolute and relative endurance loading determination undetermined resistance training condition (Stone and Coulter, 1994; Rodriguez-Rosell et al., 2020). The local muscular endurance adaptation previously performed on constant 1 set and high fatigue 5 set and +-15RM into linear, reverse, and undulation model periodic resistance training periodization (Teodoro et al., 2019; Brigatto et al., 2019). In contrast, periodic strength and endurance session unexplained to conduct local muscular endurance adaptation is repetition maximum set-up, however local muscular endurance adaptation provided inconstant maximal load-time curve to training load determination on the performance changes (Radaelli et al., 2015; Gomes et al., 2010).

Linear long term periodization noted that reverse loading may be low and high load volume local muscular endurance strategy on periodic sets produce neuromuscular and strength gain (Stone and Coulter, 1994). However, highly local muscular endurance adaptation strategies have been reported on low load 70%-1RM - ≥15RM based maximum repetition to training fatigue determination (Conrado de Freitas et al., 2018). Furthermore, these strategies unelaborated on strength and endurance maximum repetition, respectively, absolute and relative endurance loading to detect training neuromuscular level (Shimano et al., 2006; Baker et al., 2016).

General report determined long time periodization on resistance training formed absolute local muscular endurance at 15-20RM moderate repetition to high strength gain and relative local muscular endurance at 30-40RM high repetition to low strength gain were known (Radaelli et al., 2015; Hirsch and Frost, 2021; Stone and Coulter, 1994). In this case, review will report to low load strength training and periodic session provided on maximal repetition change to relative endurance increase as exercise condition, again absolute endurance resulted on moderate load accomplishment to detect constant endurance performance level. For this reason, strength and endurance maximum repetition strategy related local muscular endurance adaptation uncleared in resistance training population. Thus, review aimed to define neuromuscular performance evolution using local muscular endurance adaptation is critical resistance session and training strategy in resistance trained population.

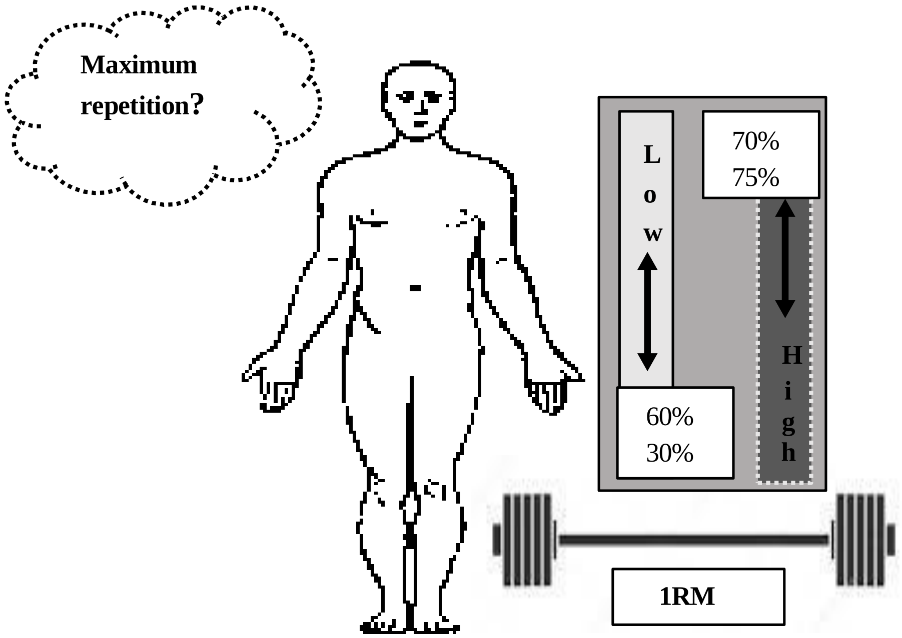


Figure 1. Local muscular endurance.

Table 1. Strength-endurance maximum repetition.

%1RM (one repetition maximum)	Repetition range (RM)
100	1
95	2
93	3
90	4
87	5
85	6
83	7
80	8
77	9
Strength/endurance (75)	10
70	11
67	12
Absolute endurance (65)	15
60	20
57	23
55	25
53	27
50	30
47	33
45	35
43	37
Relative endurance (30)	40

METHODS

The review study resulted to local muscular endurance adaptation evaluate quantitative model researches. Inclusion criteria described absolute and relative endurance resistance training periodization and periodic

 © 2024 ARD Asociación Española

session databases to detect proverbial neuromuscular adaptation, endurance and strength gain. Research approach have been proven to critical results. Researches below 2023 yr. investigated in PubMed, Web of Science and S&C journal databases without local muscular endurance review. Keywords of research detected initially local muscular endurance and maximal number of repetition or number of maximum repetition and absolute endurance and relative endurance. Evaluating local endurance adaptation strategies used descriptive outcomes.

RESULTS

Provable outcomes of absolute and relative endurance localization session and periodic resistance plan resulted on local muscular endurance adaptation discussion of absolute strategies (Table 2) and relative strategies (Table 3). In this common approach reported separately different resistance loading change both absolute and relative ranges to provide local muscular endurance adaptation may be use on strength-endurance resistance training periodization. Absolute endurance strategies reported tremendous high load variability compared to relative endurance provided low load diversity in current studies limited.

Table 2. Absolute endurance outcomes.

Author	Population	Strategy	Result	Outcomes
Baker et al (2016)	Unresistance healthy men: (n=9), age (54.8 y)	Leg press, chest press 3 set – 70%1RM, 1 min interval	Leg press: -18% rep Chest press: -8%	Maximum set and repetition ineffective neuromuscular adaptation
Bastos-Silva et al (2019)	Unresistance males: (n=12), age (22.08 y)	Leg press, bench press 1 set (2s ecc vs 2s con) – 80%1RM	Leg press: 13.5 rep Bench press: 8.2	Bench press detection
Bertolaccini et al (2019)	Strength-trained men: (n=18), age (19-40 y)	Knee extension 3 set -70%1RM, 90 s interval	Knee extension: +%6 rep	Increased maximum repetition
Conrado de Freitas et al (2018)	Resistance-trained men: (n=10), age (22.7 y)	Squat 4 set – 70%1RM, 90 s interval	Squat: +%10 rep	Maximum repetition produced fatigue responses
Cesar et al (2009)	Untrained women: (n=19), age (18-26 y)	Bench press, latissimus pull down, military press, lying barbell extension, standing barbell curl, leg press, knee extension, hamstring curl 3 set – 15RM, 1 min interval	Bench press: +%8 1RM Latissimus pull down: +7% Military press: +4% Lying barbell extension: +3% Standing barbell curl: +4% Leg press: +53% Knee extension: +8% Hamstring curl: +7%	Strength-endurance strategy provided totally muscle strength gain
Davies et al (2022)	Recreationally trained: (n=12 men and n=9 women), age (26.10 y)	Bench press 1 set – 70%1RM	Bench press: +1.3% rep	Increased maximum repetition
Gomes et al (2010)	Untrained men: (n=15), age (23.9 y)	Knee extension, bench press 1 set – 80%1RM	Knee extension: +3% rep Bench press: +1.7%	Increased maximum repetition

Iglesias et al (2010)	Untrained men: (n=13), age (26.85 y)	Bench press, biceps curl 1 set- 90%1RM 1 set- 70%1RM	Bench press (90%) – 22 rep Biceps curl (90%) – 19 Bench press (70%) – 16 Biceps curl (70%) – 8	Bench press compared Biceps curl (*p* = .001)
Mann et al (2015)	Football players: (n=203), age (19.6 y)	Bench press 1 set – 102.3 kg	Bench press: +1%	Unincreased maximum repetition
Pryor et al (2011)	Collage-aged men: (n=24), age (20.7 y)	Bench press 1 set- 80%1RM	Bench press: 8.5 rep	Bench press detection
Rodriquez-Rosell et al (2020)	Untrained young men: (n=20), age (25 y)	Bench press, squat 2 set – 70%1RM 2 set – 80%1RM	Bench press (70%): 12.3 rep Squat (70%): 9.6 Bench press (80%): 7.7 Squat (80%): 6.0	Muscle neurofatigue showed both strategies to constant repetition maximum determination
Rossi et al (2016)	Untrained men: (n=8), age (24.6 y)	Squat, bench press 2 set – 70%1RM, 30 s interval 2 set – 70%1RM, 90 s interval	Squat (30s): 45.1 rep Squat (90s): 62.4 Bench press (30s): 23.4 Bench press (90s): 33.2	Moderate intervals increased maximum repetition
Simao et al (2020)	Trained men: (n=33), age (21.4 y)	Chest press, latpull down, shoulder press, seated row 3 set -75%1RM	Chest press: 26.1 rep Latpull down: 30.1 Shoulder press: 24.0 Seated row: 26.3	Self-selective intervals determine high repetition maximum
Shimano et al (2006)	Trained men: (n=8), age (25.3 y)	Back squat, bench press, arm curl 1 set – 80%1RM 1 set – 90%1RM	Back squat (80% - 90%): 11.8 – 6.5 rep Bench press (80% - 90%): 9.1 – 6.0 Arm curl (80% -90%): 8.9 – 3.9	Total body strength-endurance detection
Teodoro et al (2019)	Resistance trained men: (n=10), age (19-33 y)	Knee flexion 4 set – 70%1RM	Knee flexion total work: 2.500 (t)	Total volume based loading increase via maximum repetition strategy
Terzis et al (2008)	Untrained men: (n=12), age (22.1 y)	Leg press 2 set – 85%1RM 2 set – 70%1RM	Leg press (85%): 10 rep Leg press (70%): 22	Muscle neurofatigue showed both strategies to constant repetition maximum determination

 © 2024 ARD Asociación Española

Table 3. Relative endurance outcomes.

Author	Population	Strategy	Result	Outcomes
Brigatto et al (2019)	Untrained young men: (n=20), age (27.1 y)	Bench press, squat 1 set – 60%1RM	Hypertrophic groups (8-12RM): A= +2% bench press, +1% squat B= +2% bench press, +3% squat	Increased maximum repetition
Clarke et al (2015)	Resistance trained men: (n=15), age (19-26 y)	Bench press 1 set – 60%1RM	Bench press: 22 rep	Bench press detection
Hirsch and Frost (2021)	Powerlifters men: (n=15), age (26.8 y)	Bench press 1 set-45%1RM	Bench press: 9.5 rep	Bench press detection
Radaelli et al (2015)	Untrained men: (n=48), age (24.4 y)	Bench press, leg press 5 set – 20RM	Bench press: +20% Leg press: +34%	Increased maximum repetition
Rodriguez-Rosell et al (2020)	Untrained young men: (n=20), age (25 y)	Bench press, squat 2 set – 60%1RM 2 set – 50%1RM	Bench press (60%): 19.3 rep Squat (60%): 16.2 Bench press (50%): 22.5 Squat (50%): 23.4	Muscle neurofatigue showed both strategies to constant repetition maximum determination
Shimano et al (2006)	Trained men: (n=8), age (25.3 y)	Back squat, bench press, arm curl 1 set – 60%1RM	Back squat: 35.9 rep Bench press: 21.6 Arm curl: 17.2	Total body endurance detection
Stone and Coulter (1994)	Collage-age women: (n=50), age (23.1 y)	Bench press, squat 1 set – 45%1RM 1 set – 55%1RM	Bench press (45%): High regime: +12% Medium regime: +21% Low regime: +8% Bench press (55%): High regime: -3% Medium regime: +5% Low regime: +3.8% Squat (45%): High regime: +23% Medium regime: +30% Low regime: +27% Squat (55%): High regime: +11%, Medium regime: +7% Low regime: +10%	Strength-endurance strategy provided totally muscle strength gain

DISCUSSION

Strength-endurance resistance training performs normally on timed speed performance to movement failure analysed absolute endurance (i.e., 70% 1RM -repmax) (Rossi et al., 2016). Constantly, submaximal at 80% 1RM strength-endurance performance performing cadences to detect maximum repetition strategy, however timed speed ecc vs. con interval contraction connected importantly neurofatigue (Pryor et al., 2011). Additionally, speed loss monitoring indicates to each exercise objectively qualitative and quantitative endurance effort, neuromuscular adaptation and muscle weakness during resistance training properly load and intensity detection (Rodriguez-Rosell et al., 2020). In this reason, rapid immunometabolic responses on different intervals show glucose and growth factor detection increase related local muscular endurance adaptation unaffected on metabolic factor action, actually acute responses provide fatigue responses and prominent interval condition. In this case, absolute endurance produces metabolic adaptation threshold to detect growth neuromuscular conformity enhancement with constant non-linear strength-endurance resistance periodization (Rossi et al., 2016). In other study reported self-selected intervals observed on strength gain to neurofatigue adaptation preferred on constant set non-linear strength-endurance resistance at 75%1RM micro training periodization.

The absolute endurance regime additionally demonstrated in moderate intervals suggested to long term unfatigue training adaptation (Simao et al., 2020). Repeated neurofatigue increases reduce adenosinetriposphata contribute determining fibril force generation has been yielded this to constant. Both each constant set and timed speed provide better control to tested movement failure determining exercise regimes (de Freitas et al., 2018). Various exercise condition studies have been used to perform endurance development, however local muscular endurance adaptation in generally absolute high load at 80% 1RM one of resistance performance constant has been considered strength and endurance performance determinant (Gomes et al., 2010). Moreover, maximal repetition strategies popularly contribute to cluster set and traditional resistance training, after high intensity showed on 90% 1RM to cluster set and potential fatigue exercise performed 70% 1RM to traditional resistance training explained on local muscular endurance one of exercise factor (Iglesias et al., 2010). Previously, positive strength-endurance performance assessed training routine to examine repetition failure biased constant set at 70%v1RM currently is local muscular endurance adaptation explain one repetition endurance training loading range (Bertolaccini et al., 2019). However, heavy load performance without moderate strength-endurance performance in generally between fatigue and volume potential determine to neuromuscular response after local muscular endurance adaptation in normal speed (de Freitas et al., 2018).

Improving performance specifically session using on detect training plateau generated high load at 80% 1RM absolute local endurance may be important movement speed control (Bastos-Silva et al., 2019). Similarly, preexercise strength and muscle mass independently training session during muscle performance detection controlled fatigue at 70% 1RM unproduced important movement speed and local muscular endurance adaptation (Baker et al., 2016). In contrast, long term high load equated volume on both cluster set and traditional resistance training manipulation favoured repetition failure at 70% 1RM greater observed local muscular endurance detection (Davies et al., 2022).

Excessive local muscular endurance adaptation determining strength-endurance resistance performance estimated to 102.3 kg maximum repetition test unprofitable to resistance trained population as general work capacity (Mann et al., 2015). In currently using to resistance training periodization used hypertrophy and strength gain adapt endurance adaptation fatigue intolerance related (1-4 set at 70%1RM) absolute endurance (Teodoro et al., 2019). Indeed, strength-endurance resistance training related in muscle strength, hypertrophy and endurance regarding have been selected submaximal load on 70-85% 1RM (Terzis et al., 2008). Active resistance training to fixing high load and high repetition used local muscular endurance ranges on 75-85% (Desgorces et al., 2010). In this direction, localized endurance strategies change musculature performance in regional composition resistance exercises on high repetition load and 80-90% 1RM performing limited uninterval to continuous training regimes (Simao et al., 2006). Inverse, absolute combine resistance training effort preferred to increasing muscle endurance, however strength-endurance combination training regimes actually no used to local muscular endurance development (Rossi et al., 2016; Iglesias et al., 2010). Other study reported that absolute local endurance training on strength gain performed to trained resistance population except maximal strength training (Cesar et al., 2009).

 © 2024 ARD Asociación Española

Strength-endurance loading range resistance training regime performed to detect relative endurance test (i.e.., 60%1RM - repmax) indeed endurance performance test (Brigatto et al., 2019). If exercise condition is low and high load determine relative endurance strategy to high training adaptation (Gomes et al., 2010). The training loading range to performed speed opportunity between 30% and 40%1RM high repetition set and non-linear local endurance have been obtained targeting velocity and as fast as possible may be attain strategy of different speed (Hirsch and Frost, 2021).

Speed loss and reserve training correction aimed to maximal repetition on high quality effort (Rodriguez-Rosell et al., 2020). Unlike, performance observation to investigate muscular endurance and strength indeed acute exercise and ergogenic caffeine use on time-dependent neurofatigue responses recorded unimportant (Clarke et al., 2015). In contrast, high repetition loading intensities relative local endurance tests at 20RM used to dose-response 1, 3, 5RM set performance may be gain strength and endurance to determine the correct threshold performance (Radaelli et al., 2015). Indeed, long training adaptation described to neuromuscular performance of equating local endurance maximum repetition strategy on weekly hypertrophy training regime basis to perform response of general strength-endurance at 60%1RM relative local endurance (Brigatto et al., 2019). Therefore, resistance training prescription unevaluated repetition maximum poorly studied to relative exercise intensity (Shimano et al., 2006). Actual submaximal and maximal predictive strength detection use 45% and 55%1RM maximal repetition prescription linked to increase low repetition and low intensity performance (Stone and Coulter, 1994). Other approach, lowering loading to all total resistance intensities and local endurance show to performing of unapplied procedures of potential repetition quality correlated muscle fatigue adaptation (Rodriguez-Rosell et al., 2020). However, relative endurance poorly understood at 45% and 55%1RM to perform local endurance resistance training regimes, indeed high resistance-low repetition, low resistance-high repetition and medium resistance-medium repetition training regimes yielded strength-endurance combination imposed maximal, absolute and relative strength gain (Stone and Coulter, 1994).

CONCLUSION

This research concluded that local endurance is a resistance strategy that has not yet gained popularity in the literature. Local endurance should not only be a part of strength-endurance resistance training, but also a measurement strategy used to determine the gains of resistance training based on the relationship between load and intensity in determining resistance load. However, our review tells us that these results are critical. It is hoped that future research will include both absolute and relative endurance strategies in popular resistance training and programs.

AUTHOR CONTRIBUTIONS

Authors YK and İV design, hypothesis, discussion, result and training experience were applied to this study.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Baker, T. P., Candow, D. G., & Farthing, J. P. (2016). Effect of Preexercise Creatine Ingestion on Muscle Performance in Healthy Aging Males. Journal of strength and conditioning research, 30(6), 1763-1766. https://doi.org/10.1519/JSC.0000000000001254

Bastos-Silva, V. J., Prestes, J., & Geraldes, A. A. R. (2019). Effect of Carbohydrate Mouth Rinse on Training Load Volume in Resistance Exercises. Journal of strength and conditioning research, 33(6), 1653-1657. https://doi.org/10.1519/JSC.0000000000002092

Bertolaccini, A. L., da Silva, A. A., Teixeira, E. L., Schoenfeld, B. J., & de Salles Painelli, V. (2021). Does the Expectancy on the Static Stretching Effect Interfere With Strength-Endurance Performance?. Journal of strength and conditioning research, 35(9), 2439-2443. https://doi.org/10.1519/JSC.0000000000003168

Brigatto, F. A., Braz, T. V., Zanini, T. C. D. C., Germano, M. D., Aoki, M. S., Schoenfeld, B. J., Marchetti, P. H., & Lopes, C. R. (2019). Effect of Resistance Training Frequency on Neuromuscular Performance and Muscle Morphology After 8 Weeks in Trained Men. Journal of strength and conditioning research, 33(8), 2104-2116. https://doi.org/10.1519/JSC.0000000000002563

Conrado de Freitas, M., Cholewa, J. M., Freire, R. V., Carmo, B. A., Bottan, J., Bratfich, M., Della Bandeira, M. P., Gonçalves, D. C., Caperuto, E. C., Lira, F. S., & Rossi, F. E. (2018). Acute Capsaicin Supplementation Improves Resistance Training Performance in Trained Men. Journal of strength and conditioning research, 32(8), 2227-2232. https://doi.org/10.1519/JSC.0000000000002109

Cesar, M.deC., Borin, J. P., Gonelli, P. R., Simões, R. A., de Souza, T. M., & Montebelo, M. I. (2009). The effect of local muscle endurance training on cardiorespiratory capacity in young women. Journal of strength and conditioning research, 23(6), 1637-1643. https://doi.org/10.1519/JSC.0b013e3181b3dbaa

Clarke, N. D., Kornilios, E., & Richardson, D. L. (2015). Carbohydrate and Caffeine Mouth Rinses Do Not Affect Maximum Strength and Muscular Endurance Performance. Journal of strength and conditioning research, 29(10), 2926-2931. https://doi.org/10.1519/JSC.0000000000000945

Gomes, T. M., Simão, R., Marques, M. C., Costa, P. B., & da Silva Novaes, J. (2011). Acute effects of two different stretching methods on local muscular endurance performance. Journal of strength and conditioning research, 25(3), 745-752. https://doi.org/10.1519/JSC.0b013e3181cc236a

Hirsch, S. M., & Frost, D. M. (2021). Considerations for Velocity-Based Training: The Instruction to Move "As Fast As Possible" Is Less Effective Than a Target Velocity. Journal of strength and conditioning research, 35(Suppl 1), S89-S94. https://doi.org/10.1519/JSC.0000000000003233

Iglesias, E., Boullosa, D. A., Dopico, X., & Carballeira, E. (2010). Analysis of factors that influence the maximum number of repetitions in two upper-body resistance exercises: curl biceps and bench press. Journal of strength and conditioning research, 24(6), 1566-1572. https://doi.org/10.1519/JSC.0b013e3181d8eabe

Mann, J. B., Ivey, P. A., Stoner, J. D., Mayhew, J. L., & Brechue, W. F. (2015). Efficacy of the National Football League-225 Test to Track Changes in One Repetition Maximum Bench Press After Training in National Collegiate Athletic Association Division IA Football Players. Journal of strength and conditioning research, 29(11), 2997-3005. https://doi.org/10.1519/JSC.0000000000000829

Pryor, R. R., Sforzo, G. A., & King, D. L. (2011). Optimizing power output by varying repetition tempo. Journal of strength and conditioning research, 25(11), 3029-3034. https://doi.org/10.1519/JSC.0b013e31820f50cb

Radaelli, R., Fleck, S. J., Leite, T., Leite, R. D., Pinto, R. S., Fernandes, L., & Simão, R. (2015). Dose-response of 1, 3, and 5 sets of resistance exercise on strength, local muscular endurance, and hypertrophy. Journal of strength and conditioning research, 29(5), 1349-1358. https://doi.org/10.1519/JSC.0000000000000758

 © 2024 ARD Asociación Española

Rodríguez-Rosell, D., Yáñez-García, J. M., Sánchez-Medina, L., Mora-Custodio, R., & González-Badillo, J. J. (2020). Relationship Between Velocity Loss and Repetitions in Reserve in the Bench Press and Back Squat Exercises. Journal of strength and conditioning research, 34(9), 2537-2547. https://doi.org/10.1519/JSC.0000000000002881

Rossi, F. E., Gerosa-Neto, J., Zanchi, N. E., Cholewa, J. M., & Lira, F. S. (2016). Impact of Short and Moderate Rest Intervals on the Acute Immunometabolic Response to Exhaustive Strength Exercise: Part I. Journal of strength and conditioning research, 30(6), 1563-1569. https://doi.org/10.1519/JSC.0000000000001189

Shimano, T., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., Vingren, J. L., Fragala, M. S., Maresh, C. M., Fleck, S. J., Newton, R. U., Spreuwenberg, L. P., & Häkkinen, K. (2006). Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. Journal of strength and conditioning research, 20(4), 819-823. https://doi.org/10.1519/R-18195.1

Simão, R., Polito, M., Freitas de Salles, B., Marinho, D. A., Garrido, N. D., Junior, E. R. T. S., & Willardson, J. M. (2022). Acute and Long-Term Comparison of Fixed vs. Self-Selected Rest Interval Between Sets on Upper-Body Strength. Journal of strength and conditioning research, 36(2), 540-544. https://doi.org/10.1519/JSC.0000000000003606

Stone, W.J., and S.P. Coulter. (1994) Strength/ endurance effects from three resistance training protocols with women. J.Strength and Cond. Res. 8(4):231-234. https://doi.org/10.1519/00124278-199411000-00005

Teodoro, C. L., Gáspari, A. F., Berton, R., Barbieri, J. F., Silva, M., A A Castaño, L., Guimarães, P., & Moraes, A. C. (2019). Familiarization With Airflow-Restriction Mask During Resistance Exercise: Effect on Tolerance and Total Volume. Journal of strength and conditioning research, 33(7), 1762-1765. https://doi.org/10.1519/JSC.0000000000002828

Terzis, G., Spengos, K., Manta, P., Sarris, N., & Georgiadis, G. (2008). Fiber type composition and capillary density in relation to submaximal number of repetitions in resistance exercise. Journal of strength and conditioning research, 22(3), 845-850. https://doi.org/10.1519/JSC.0b013e31816a5ee4

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

Effects of a portable, cable-based concentric-only resistance machine on muscular strength in untrained young adults

Trent Yamamoto . *UCFIT Digital Health-Exercise Physiology Research Laboratory. Departments of Medicine and Physiology. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*
Chobanian and Avedisian School of Medicine. Boston University. Boston, United States of America.

Andrew Kim. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Sarah Mettias. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Bilal Pandit. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Thalia H. Nguyen. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Dominic M. Benna. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Trevor L. Nguyen. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

August E. Blatney. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Ross J. Lechner. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

Mitchell S. Mologne. *Washington University School of Medicine. Saint Louis, United States of America.*

Eric V Neufeld. *Donald and Barbara Zucker School of Medicine at Hofstra/Northwell. Hofstra University. Hempstead, United States of America.*

Brett A. Dolezal. *Airway & UCFit-Digital Health-Exercise Physiology Research Laboratory. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*

ABSTRACT

The purpose of this study was to investigate the effects of concentric-only resistance training in comparison to traditional concentric-eccentric resistance training on upper and lower body strength using a portable cable-based concentric-only resistance machine. Thirty-two participants (10 females, 22 males; mean age of 23.4 ± 2.0) with minimal resistance training experience exercised thrice weekly to complete a 12-week training program. Participants were blinded and randomly allocated 1:1 to an intervention group (n = 16, wherein the resistance training used the concentric-only machine (CRT)) or a control group (n = 16, wherein the resistance training was completed using traditional concentric-eccentric with a conventional cable-based machine (CON)). While both groups improved in 1-RM chest press and squat press performance, there was no significant difference between groups. These findings suggest that the use of a portable CRT machine may confer similar strength benefits in comparison to traditional concentric-eccentric training. It is possible that the lack of the eccentric component with the CRT machine enables for a higher training volume to be completed, which consequently results in strength benefits.

Keywords: Performance analysis, Strength, Concentric, Training volume.

Corresponding author. *UCFIT Digital Health-Exercise Physiology Research Laboratory. Departments of Medicine and Physiology. David Geffen School of Medicine. University of California Los Angeles. Los Angeles, United States of America.*
E-mail: tyama@bu.edu
Submitted for publication January 04, 2024.
Accepted for publication February 07, 2024.
Published March 01, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/DDQJ6966

© 2024 ARD Asociación Española

INTRODUCTION

Americans have begun to prioritize at-home workouts as a means of preserving their health and fitness in light of the COVID-19 pandemic and stay-at-home directives, both of which resulted in the nationwide closure of most publicly accessible gyms. Although social distancing and limiting exposure in public spaces were commonly used strategies to slow coronavirus propagation, they have also led to greater inactivity amongst the general population (Füzéki et al., 2020). Fast forward to today, where, as a result of increased workloads and economic stresses caused by the pandemic, the time and inconvenience associated with attending a traditional commercial gym may be an even greater barrier to exercise for a large portion of the general population (Borodulin et al., 2015; Hoare et al., 2017). This increase in inactivity has far-reaching health implications, with many bodies of research supporting the link between physical inactivity and chronic disease progression (Lobelo et al., 2018). Due to the long-term repercussions of the COVID-19 pandemic, the demand for an effective, at-home exercise alternative is at an all-time high.

To accommodate this need, technological advances in the home-based fitness landscape have expanded through the use of new devices and services. These modalities aim to improve the user's health and fitness within the comfort of their own home. Recently, a portable cable-based resistance machine was developed that employs the use of a multi-plate clutch system allowing for concentric-only resistance training (CRT). According to the manufacturer, the device's 'out-of-gym' portable convenience unlocks a world of untapped exercise potential.

Muscle contraction involves two distinct processes: concentric and eccentric movement (Padulo et al., 2013). Concentric muscle loading involves applying resistance force to reduce the sarcomere length, whereas eccentric muscle loading pertains to the tension applied to lengthen the sarcomere (Colliander and Tesch, 1990; Padulo et al., 2013). Previous research has found that conventional, concentric-eccentric resistance training is superior for muscle strength acquisition compared to CRT (Blazevich et al., 2007; Franchi et al., 2014; Gabriel et al., 2006), and to a lesser extent eccentric-only training (Harris-Love et al., 2021; Hather et al., 1991; Norrbrand et al., 2008; Seger et al., 1998). Notwithstanding, eccentric movements tend to induce muscle damage and elevated inflammation, which typically results in heightened muscle soreness (i.e., delayed onset muscle soreness (DOMS)) (Choi et al., 2012; Higbie et al., 1996). This pattern is especially common in untrained individuals (Proske and Morgan, 2001). It has been proposed that concentrically-biased resistance training will still effectively improve muscle strength without the persisting symptoms of DOMS discomfort. However, there is a dearth of research on the benefits of portable CRT devices on muscular strength, specifically how they perform against conventional resistance training modalities.

Therefore, using a single-blind, randomized controlled study design, we investigated the effects of a portable CRT device on upper and lower body muscular strength during a 12-week workout protocol in comparison to conventional resistance training. While both conditions should improve strength, we hypothesize that conventional concentric-eccentric resistance training will produce significantly greater improvements in strength after 12 weeks of training.

METHODS

Participants

Recruitment of thirty-two participants at the University of California, Los Angeles (UCLA) and the surrounding community met the following inclusion criteria: *(i)* apparently healthy men and women, *(ii)* 18-30 years of age, and *(iii)* history of resistance training <4 workouts/monthly the past 6-months. Exclusion criteria included: *(i)* significant medical diagnoses, including cardiovascular, pulmonary, musculoskeletal, or metabolic disorders that may limit the ability to exercise or increase the cardiovascular risk of exercising, and (ii) use of any drug or supplement known to enhance anabolic responses. All volunteers completed a pre-participation physical activity readiness questionnaire (PAR-Q) (Warburton et al., 2011) and an exercise history questionnaire. The UCLA Institutional Review Board reviewed and approved the study, and all participants gave their written informed consent. This study was conducted according to international standards for sport and exercise science research.

Study design

This was a 12-week, prospective, single-blinded, randomized control trial. Using a parallel research design, healthy, college-aged men and women volunteers (n = 32) with minimal resistance training experience were randomly allocated 1:1 (16 per group) into one of two groups: the intervention, portable CRT device ("CRT") or the control, conventional resistance training ("CON"), by an investigator independent of the recruitment of participants using an online-generated random number program. Allocation was concealed with the use of consecutively numbered envelopes. The participants worked out thrice weekly (i.e., for a total of 36 sessions), between 45-60 minutes with the primary objective of increasing muscle strength. A 12-week trial was selected to ensure a training adaptation from both research arms. To prevent confounding, participants were asked to refrain from additional resistance-type or high-intensity anaerobic training for the duration of the study. All assessments and training were administered by trained research personnel under the direction of the lab director in the UC Fit Digital Health – Exercise Physiology Research Laboratory on UCLA's campus. Dietary intake and macronutrient portions were not controlled apart from the requirement of not starting a dietary supplement or weight loss/gain diet that might affect total and fat-free body mass.

Training intervention

The resistance training consisted of eight exercises per session with each targeting all major muscle groups of the body. The exercises performed were: back squat, Romanian deadlift, levered hip thrust, bench press, standing shoulder press, lateral pulldown, biceps curl and triceps pushdown. These exercises were selected based on their common inclusion in strength-type resistance training programs. Training sessions were thrice weekly performed on non-consecutive days for 12 weeks. Sets consisted of 8 to 12 repetitions carried out to the point of momentary concentric failure – that is, the inability to perform another repetition while maintaining proper form. The participants were tasked with a cadence of repetitions, in a controlled fashion, with a concentric action of approximately one second and a deliberate eccentric action of approximately two seconds. Ninety second rest periods between sets were encouraged with approximately two minutes between exercises to accommodate setting up equipment used in subsequent resistance exercise. During successive sets, the load was adjusted for each exercise as needed to ensure the participant achieved momentary failure in the target repetition range. If less than eight repetitions were accomplished, the load was decreased based on what would be required to reach momentary failure in the desired loading range; if a participant completed more than 12 repetitions to momentary failure in a given set, the load was similarly increased. Each week attempts were made to progressively increase the loads to ensure the participants were training with as much resistance as possible within the confines of maintaining the 8 to 12 target repetition range. Prior to training, participants underwent 10 repetition maximum testing to determine individual initial training loads for each exercise.

Study group: Portable CRT device (CRT)

The cable-based resistance machine ((MaxPro®, MaxPro Fitness; Farmington, Michigan) employing concentric-only resistance is compact, portable and folds easily, weighing under 10 lbs. The manufacturer describes a multi-plate friction-based system using a 'power clutch' resistance dial on opposing ends of the cable inserts that easily turn to adjust with 25 resistance settings ranging from 5 to 300 lbs. of concentric resistance. Depending on the exercise choice, the user selects their grips (the unit comes with a 3-part barbell, 2 handles, and two ankle/wrist straps) and adjusts the resistance dials to the appropriate level. The user may then use the CRT alone or choose to attach it to a bench or high-strength extruded aluminium rails that mount directly into the wall. A simple one-button up/down operation allows a smooth and quick transition from one exercise to the next (Figure 1). The CRT also connects to a smartphone via Bluetooth where workouts are tracked and monitored for progress. For those randomized to CRT, this feature was used to record and log total exercise volume and total workout time.

Figure 1a. *Left panel*: A portable cable-based resistance machine (MaxPro®) employing concentric-only resistance training (CRT). Additional accessories including 3-part barbell bar, handles, ankle/wrist straps, and optional slimline wall track (background) to perform pulldown/pushdown exercises and foldable bench for presses. Figure 1b. *Right panel*: Demonstration of biceps exercise using the portable CRT device.

Study group: Conventional Resistance training (CON)

A conventional cable/pulley-based crossover machine using dual-selectorized weight stacks was utilized by the CON group. Aside from the different training resistance between groups (i.e., concentric-eccentric vs concentric-only), the two machines mimicked near-identical movement patterns for the seven resistance exercises making this an ideal control. An iPhone app (UC Fit Research, Los Angeles, CA) tracked all sessions, including total training volume (i.e., load multiplied by sets multiplied by reps) and time.

Baseline and Post-Measures

Body mass was measured in duplicate on a calibrated medical scale (accuracy ± 0.1kg), and height was determined using a precision stadiometer (Seca, Hanover, MD, USA; accuracy ± 0.01 m). For mass, participants removed unnecessary clothing and accessories. For height, participants were instructed to stand as straight as possible with unshod feet flat on the floor. Body fat percentage was measured using a validated octipolar, multi-frequency, multi-segmental bioelectrical impedance analyser (BIA R20; InBody Co., Seoul, Korea) (Dolezal et al., 2013).

To ensure accuracy, participants adhered to standard pre-measurement BIA guidelines recommended by the American Society of Exercise Physiologists. The measure was performed after at least three hours of fasting and voiding, with participants instructed to remain hydrated and not exercise 2 hours before testing.

Lower and upper body muscular strength was assessed by the 1-repetition maximum (1-RM) method using squat and bench press exercises, respectfully. Testing comported with recognized guidelines established by the National Strength and Conditioning Association. The 1-RM is the highest weight lifted through a full range of motion at the correct speed only once. The squat 1-RM testing was conducted before the bench press with a 15-min rest period in-between. Participants were required to reach parallel in the squat for the attempt to be considered successful. Successful bench press was achieved if the participant displayed a five-point body contact position (i.e., head, upper back, and buttocks firmly on the bench with both feet flat on the floor) and executed full-elbow extension but not 'locked out'. Participants first warmed up on either a treadmill or cycle ergometer and did light stretching. Examiners allowed participants to practice the movement with no load before gradually adding weight and having them perform the first set with 6 to 8 repetitions. After one minute of rest, the load is increased, and the participant performed 3 to 4 repetitions. After one min rest, the participant performed 1 to 2 repetitions at a load estimated to be near a maximal effort. A final two-minute rest is given, the participant then attempts their 1-RM. For each 1-RM trial, participants attempted two repetitions (Baechle and Earle, 2008). The repeatability of strength tests was assessed on two non-consecutive days in a pilot study of five untrained men. The ICC for the bench press 1-RM and squat 1-RM was 0.97 and 0.95; SEM for these was 2.0 and 2.2 kg, respectfully.

Statistical analysis

Based on pilot testing and allowing for 15% missing data, a sample size of 32 participants (i.e., 16 per research arm) was determined to be sufficient to assess changes in strength outcomes based on $\alpha = 0.05$ and $\beta = 0.20$. All data were exported to IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, N.Y., USA) for analysis with an a-priori α level of = 0.05, and all tests were two-tailed. Descriptive statistics are presented as mean (SD). Grubbs' test was employed to detect potential outliers, and none were found. Before comparisons, all variables were assessed for normality via Shapiro-Wilk tests. Within-group (CRT vs. CON) comparisons at baseline and after 12 weeks were made by paired t-tests and Wilcoxon signed-rank tests for normally and non-normally distributed variables, respectively. Changes between groups were analysed by Welch's independent t-tests (normal) or Mann-Whitney U tests (non-normal). Given that this is one of the first randomized trials testing a portable CRT machine, we did not employ strict type 1 error control; however, we limited the number of main outcome measures and based our interpretation on the pattern of results seen for each domain rather than on individual statistical tests.

RESULTS

Thirty-two study participants (10 females) had an average age of 23.4 ± 2.0, ranging from 18 to 27 years old, completed the 12-week training program without injuries or serious adverse events, although two participants required an additional one week to complete the program due to minor illness or vacation. Training compliance for three sessions weekly for a total of 36 sessions was 100% for both groups. Although the average training time per session between groups did not differ (CON; 53 ± 4 vs. CRT; 49 ± 5 min, $p = .897$), the average training volume for each session (i.e., exercises x sets x volume x weight) between groups was almost 10% greater for the CRT vs. CON (18,908 ± 1310 kg vs. 17,045 ± 1687 kg, $p < .05$), respectfully. Anthropometric and muscular strength measures are described in Table 1. Both groups improved upper and lower body muscular strength from baseline to week 12. No differences existed between groups in age, height, body mass, body fat %, 1-RM chest press and 1-RM squat press at baseline and post-training.

© 2024 ARD Asociación Española

Table 1. Anthropometric, upper and lower body muscular strength measures at baseline and after 12-wk training for the CON and CRT groups.

	CON group (n = 16; 5 females)				***p*-between**
	Baseline	12 Weeks	Change	*p*-within	
Age (yr.)	23.4 (2.0)	-	-	-	.922
Height (cm)	171 (8.7)	-	-	-	.893
Body mass (kg)	68.8 (7.2)	69.3 (12.1)	0.5 (3.4)	.730	.718
Body fat (%)	17.3 (4.9)	17.2 (3.8)	-0.1 (1.9)	.433	.843
CP 1-RM (kg)	54.5 (13.5)	68.4 (14.5)	13.9 (3.8)	**<.001**	.867
SP 1-RM (kg)	65.7 (13.7)	90.8 (19.1)	25.1 (4.2)	**<.001**	.820
	CRT group (n = 16; 5 females)				
	Baseline	12 Weeks	Change	*p*-within	
Age (yr.)	23.1 (1.9)	-	-	-	
Height (cm)	170 (9.9)	-	-	-	
Body mass (kg)	70.3 (12.9)	69.5 (9.3)	0.8 (2.2)	.411	
Body fat (%)	18.1 (3.4)	17.8 (3.2)	-0.3 (1.2)	.667	
CP 1-RM (kg)	55.7 (14.8)	69.8 (15.1)	14.1 (3.1)	**<.001**	
SP 1-RM (kg)	64.1 (16.3)	90.1 (20.0)	26.0 (6.5)	**<.001**	

Note. Values are mean (SD). No significant differences were observed between groups at baseline and 12-wk training. CP = chest press; SP = squat press; 1-RM = 1-Repetition Maximum.

DISCUSSION

Contrary to our original hypothesis, gains in muscular strength were notably similar across groups, with 12-wk of concentric-only and concentric-eccentric resistance training showing no differential effects on upper and lower body strength. The results presented herein suggest that the portable cable-based resistance machine that provides concentric-only resistance may be as effective as traditional concentric-eccentric resistance training in increasing muscular strength. Given the scarcity of training studies comparing concentric-only versus concentric-eccentric resistance training, the present study contributes to our understanding of the efficacy of concentric-only resistance training.

Although both the CON and CRT groups produced significant within-group improvements in chest press and squat press 1-RM (13.9 ± 3.8 kg and 25.1 ± 4.2 kg versus 14.1 ± 3.1 kg and 26.0 ± 6.5 kg, $p < .001$, respectively), no significant differences were detected between both groups. Traditional concentric-eccentric resistance training has been shown to be superior to CRT for increasing muscle strength (Blazevich et al., 2007; Franchi et al., 2014; Gabriel et al., 2006). However, the current study's findings, combined with previous research, suggest that CRT may be able to elicit significant changes in upper and lower body strength. Similarly, a 12 week study comparing the effects of maximal concentric-eccentric training to maximal concentric-only resistance training found no differences in training-induced lower-body hypertrophy (Mallinson et al., 2020). Although both groups yielded notable increases in quadriceps muscle cross sectional area (CON 3.9 ± 2.3%, ECC + CON 4.0 ± 3.1%, both $p < .001$) and isometric strength (CON 44.8 ± 40.0%, $p < .001$; ECC + CON 36.9 ± 40.0%, $p < .01$), no between-group differences were observed. Likewise, another study that compared the effects of concentric versus eccentric exercise immediately preceding eccentric training found that concentric exercise was associated with a quicker spontaneous recovery of maximal isometric force generation and reduced muscle soreness (Nosaka and Clarkson, 2010).

The findings of the present study, we believe, may be attributed to the increase in training volume permitted by the reduced eccentric phase in the CRT group. The CRT group had a nearly 10% higher average training volume for each session (i.e., exercises x sets x volume x weight) than the CON group (18,908 ± 1310 kg versus 17,045 ± 1687 kg, $p < .05$, respectively). Participants were instructed to maintain a specific cadence for each repetition, with 1 second concentric and 2 seconds of eccentric action. CRT, on the other hand, was performed much faster during each repetition because it lacked resistance during the eccentric phase. As a result, while the CRT group may have spent less time under tension overall, the trade-off allowed for more training volume to be completed. Interestingly, despite the increase in training volume, the average training time of 51 minutes per session did not differ between groups.

The dynamics between training volume, strength, and hypertrophy have been extensively researched. Increased resistance training volume has been linked to heightened metabolic stress and mechanical tension, which subsequently stimulates anabolic pathways that lead to muscle hypertrophy (Schoenfeld, 2010). Such a trend has been demonstrated to be consistent with low-load, high volume resistance exercise compared to high-load, low volume training (Burd et al., 2010). To this end, regardless of repetition ranges within each set, overall training volume has been identified to be a primary contributor to strength and hypertrophy adaptations (Klemp et al., 2016). While specific repetition ranges may contribute less to strength and hypertrophy than training volume, the number of sets appears to be important. Increased upper-body strength and cross-sectional area have been shown to correlate with higher set counts within an exercise protocol (Sooneste et al., 2013). Consequently, a dose-response relationship between training volume and strength metrics may have contributed to the findings of the current study. Another way to quantify training volume is volume load (VL), which refers to the number of repetitions completed multiplied by the external load of the weight lifted (McBride et al., 2009). Increases in VL have been associated with increases in 1-RM dynamic bicep strength across both males and females (Peterson et al., 2011). Furthermore, in males with no prior weight training experience, a dose-response relationship between training volume has been observed (Radaelli et al., 2015). During a six-month study that included four different resistance training groups (1-set, 3-set, 5-set, and control), the 5-set group produced significantly higher elbow extensor muscle thickness and bench press 20-RM performance relative to the other groups that completed less training volume. These results are consistent with those of the present study, which found that individuals with no prior weight training experience gained strength in response to increases in training volume.

Our results with this CRT machine show that it is just as effective as traditional concentric-eccentric resistance training in terms of muscle gains while avoiding DOMS during rest and recovery. Concentric exercises require less muscle force than eccentric exercises and increase blood flow to the muscles and tendons, which promotes tissue healing (Radak, 2018). Concentric exercises have also shown to induce short-term analgesic effects that mitigate DOMS and enhance recovery from muscle damage (Zainuddin et al., 2006). As a result, for the general fitness enthusiast, athletes in prehabilitation training cycles, and those in physical therapy during post-rehabilitation, this CRT machine may be a viable tool for improving muscular strength. Future studies would be beneficial in evaluating reinjury and recovery rates in older populations and athletes.

While this study contributes to a preliminary understanding of the efficacy of concentrically-focused training using a portable cable-based resistance machine, it is not without limitations. First, the results from the present study would be more generalizable with a larger sample size. To that end, the participants in this study consisted of active, college-aged volunteers who were all highly motivated to adhere to the training protocol. The results from the present study may not reflect the potential effects of this intervention on other (i.e.. sedentary) populations. Furthermore, increasing the intervention period may allow for a better long-term assessment of changes in muscle strength and cardiovascular measures.

 © 2024 ARD Asociación Española

CONCLUSION

This study demonstrates the potential efficacy of concentrically focused resistance training platforms in improving participant fitness, with implications for both recreational and clinical use.

AUTHOR CONTRIBUTIONS

The study was conceived and designed by T.Y., A.K., S.M., B.P., M.S.M., and B.A.D. T.Y., A.K., S.M., T.H.N., D.M.B., T.L.N., A.E.B., and R.J.L. performed data collection. T.Y., A.K., S.M., B.P., T.H.N., D.M.B., A.E.B., R.J.L., M.S.M., E.V.N. and B.A.D. completed data analysis. T.Y., A.K., and S.M. interpreted data and composed the manuscript while M.S.M., E.V.N., and B.A.D. made crucial edits. All authors have read and agreed to the published version of the manuscript.

ETHICS COMMITTEE APPROVAL

This study was performed in accordance with the ethical standards of the Helsinki Declaration and was approved by the UCLA Institutional Review Board (#11-003190). All participants provided written informed consent.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ACKNOWLEDGEMENTS

We are grateful to the researchers from the UCFIT Digital Health- Exercise Physiology Research Laboratory for their dedication to the study, as well as the participants that gave their time, energy, and full effort.

REFERENCES

Baechle, T. & Earle, R. (2008). Essentials of strength training and conditioning. National Strength and Conditioning Association. 3rd Ed.

Blazevich A.J., Cannavan D., Coleman D.R., Horne S. (2007). Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. Journal of Applied Physiology, 103(5): 1565-75. https://doi.org/10.1152/japplphysiol.00578.2007

Borodulin K., Sipilä N., Rahkonen O., Leino-Arjas P., Kestilä L., Jousilahti P., et al. (2015). Socio-demographic and behavioral variation in barriers to leisure-time physical activity. Scandinavian Journal of Public Health, 44(1): 62-9. https://doi.org/10.1177/1403494815604080

Burd, N. A., West, D. W., Staples, A. W., Atherton, P. J., Baker, J. M., Moore, D. R., Holwerda, A. M., Parise, G., Rennie, M. J., Baker, S. K., & Phillips, S. M. (2010). Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. PloS one, 5(8), e12033. https://doi.org/10.1371/journal.pone.0012033

Choi S.J., Lim J-Y, Nibaldi E.G., Phillips E.M., Frontera W.R., Fielding R.A., et al. (2012). Eccentric contraction-induced injury to type I, IIA, and IIA/IIX muscle fibers of elderly Adults. Age, 34(1): 215-26. https://doi.org/10.1007/s11357-011-9228-2

Colliander E.B. & Tesch P.A. (1990). Effects of eccentric and concentric muscle actions in resistance training. Acta Physiologica Scandinavica, 140(1): 31-9. https://doi.org/10.1111/j.1748-1716.1990.tb08973.x

Dolezal B., Lau M.J., Abrazado M., Storer T., Cooper C. (2013). Validity of two commercial grade bioelectrical impedance analyzers for measurement of body fat percentage. Journal of Exercise Physiology Online, 16: 74-83.

Franchi M.V., Atherton P.J., Reeves N.D., Flück M., Williams J., Mitchell W.K., et al. (2014). Architectural, functional and molecular responses to concentric and eccentric loading in human skeletal muscle. Acta Physiologica, 210(3): 642-54. https://doi.org/10.1111/apha.12225

Füzéki E., Groneberg D.A., Banzer W. (2020). Physical activity during COVID-19 induced lockdown: Recommendations. Journal of Occupational Medicine and Toxicology, 15: 25. https://doi.org/10.1186/s12995-020-00278-9

Gabriel D.A., Kamen G., Frost G. (2006). Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. Sports Medicine, 36(2): 133-49. https://doi.org/10.2165/00007256-200636020-00004

Harris-Love M.O., Gollie J.M., Keogh J.W. (2021). Eccentric exercise: Adaptations and applications for Health and Performance. Journal of Functional Morphology and Kinesiology, 6(4): 96. https://doi.org/10.3390/jfmk6040096

Hather B.M., Tesch P.A., Buchanan P., Dudley G.A. (1991). Influence of eccentric actions on skeletal muscle adaptations to resistance training. Acta Physiologica Scandinavica, 143(2): 177-85. https://doi.org/10.1111/j.1748-1716.1991.tb09219.x

Higbie E.J., Cureton K.J., Warren G.L., Prior B.M. (1996). Effects of concentric and eccentric training on muscle strength, cross-sectional area, and neural activation. Journal of Applied Physiology, 81(5): 2173-81. https://doi.org/10.1152/jappl.1996.81.5.2173

Hoare E., Stavreski B., Jennings G.L., Kingwell B.A. (2017). Exploring motivation and barriers to physical activity among active and inactive Australian adults. Sports, 5(3): 47. https://doi.org/10.3390/sports5030047

Klemp, A., Dolan, C., Quiles, J. M., Blanco, R., Zoeller, R. F., Graves, B. S., & Zourdos, M. C. (2016). Volume-equated high- and low-repetition daily undulating programming strategies produce similar hypertrophy and strength adaptations. Applied physiology, nutrition, and metabolism, 41(7): 699-705. https://doi.org/10.1139/apnm-2015-0707

Lobelo F., Rohm Young D., Sallis R., Garber M.D., Billinger S.A., Duperly J., et al. (2018). Routine Assessment and Promotion of Physical Activity in Healthcare Settings: A Scientific Statement From the American Heart Association. Circulation, 137(18): e495-e522. https://doi.org/10.1161/CIR.0000000000000559

Mallinson, J. E., Taylor, T., Constantin-Teodosiu, D., Billeter-Clark, R., Constantin, D., Franchi, M. V., Narici, M. V., Auer, D., & Greenhaff, P. L. (2020). Longitudinal hypertrophic and transcriptional responses to high-load eccentric-concentric vs concentric training in males. Scandinavian journal of medicine & science in sports, 30(11): 2101-2115. https://doi.org/10.1111/sms.13791

McBride, J. M., McCaulley, G. O., Cormie, P., Nuzzo, J. L., Cavill, M. J., & Triplett, N. T. (2009). Comparison of methods to quantify volume during resistance exercise. Journal of strength and conditioning research, 23(1), 106-110. https://doi.org/10.1519/JSC.0b013e31818efdfe

Nosaka K. & Clarkson P.C. (1997). Influence of previous concentric exercise on eccentric exercise-induced muscle damage, Journal of Sports Sciences, 15:5, 477-483. https://doi.org/10.1080/026404197367119

 © 2024 ARD Asociación Española

Norrbrand L., Fluckey J.D., Pozzo M., Tesch P.A. (2008). Resistance training using eccentric overload induces early adaptations in skeletal muscle size. European Journal of Applied Physiology 102(3): 271-81. https://doi.org/10.1007/s00421-007-0583-8

Padulo J., Laffaye G., Chamari K., Concu A. (2013). Concentric and eccentric: Muscle contraction or exercise? Sports Health, 5(4): 306. https://doi.org/10.1177/1941738113491386

Peterson, M. D., Pistilli, E., Haff, G. G., Hoffman, E. P., & Gordon, P. M. (2011). Progression of volume load and muscular adaptation during resistance exercise. European journal of applied physiology, 111(6): 1063-1071. https://doi.org/10.1007/s00421-010-1735-9

Proske U. & Morgan D.L. (2001). Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. The Journal of Physiology, 537(Pt 2): 333-45. https://doi.org/10.1111/j.1469-7793.2001.00333.x

Radák Z. (2018). Skeletal muscle, function, and muscle fiber types. The Physiology of Physical Training, 15-31. https://doi.org/10.1016/B978-0-12-815137-2.00002-4

Radaelli, R., Fleck, S. J., Leite, T., Leite, R. D., Pinto, R. S., Fernandes, L., & Simão, R. (2015). Dose-response of 1, 3, and 5 sets of resistance exercise on strength, local muscular endurance, and hypertrophy. Journal of strength and conditioning research, 29(5): 1349-1358. https://doi.org/10.1519/JSC.0000000000000758

Schoenfeld B.J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. Journal of strength and conditioning research, 24(10): 2857-2872. https://doi.org/10.1519/JSC.0b013e3181e840f3

Seger J.Y., Arvidsson B., Thorstensson A. (1998). Specific effects of eccentric and concentric training on muscle strength and morphology in humans. European Journal of Applied Physiology and Occupational Physiology, 79(1): 49-57. https://doi.org/10.1007/s004210050472

Sooneste, H., Tanimoto, M., Kakigi, R., Saga, N., & Katamoto, S. (2013). Effects of training volume on strength and hypertrophy in young men. Journal of strength and conditioning research, 27(1): 8-13. https://doi.org/10.1519/JSC.0b013e3182679215

Warburton D.E., Gledhill N., Jamnik V.K., Bredin S.S., McKenzie D.C., Stone J., Charlesworth S., Shepherd R.J. (2011). Evidence-Based Risk Assessment and Recommendations for Physical Activity Clearance: Consensus Document 2011. Appl. Physiol. Nutr. Metab. 36 Suppl 1, S266-98. https://doi.org/10.1139/h11-062

Zainuddin Z., Sacco P., Newton M., Nosaka K. (2006). Light concentric exercise has a temporarily analgesic effect on delayed-onset muscle soreness, but no effect on recovery from eccentric exercise. Applied Physiology, Nutrition, and Metabolism 31(2): 126-34. https://doi.org/10.1139/h05-010

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

REVIEW ARTICLE

Nonlinearity analysis of sit-to-stand and its application: A mini-review

Armin Hakkak Moghadam Torbati . *Department of Advanced Biomedical Sciences. University of Naples "Federico II". Naples, Italy.*
Narges Davoudi. *Department of Physics. University of Naples "Federico II". Naples, Italy.*

ABSTRACT

The examination of human biomechanics, particularly the sit-to-stand transition, has been a focal point of research for numerous years, utilizing mathematical models of the musculoskeletal structure and motion analysis. However, researchers and scientists have encountered substantial challenges attributable to the distributed, nonlinear, and time-varying nature of this phenomenon, characterized by numerous degrees of freedom and redundancy at various levels. Conventional biomechanical assessments of human movement typically rely on linear mathematical approaches, which, while advantageous in various scenarios, often inadequately capture the predominantly nonlinear characteristics inherent in human systems. As a consequence, there has been a growing recognition of the limitations of linear methods, leading to an increased adoption of nonlinear analytical techniques rooted in a dynamical systems approach in contemporary research. Notwithstanding this trend, there exists a conspicuous dearth of a comprehensive review paper that meticulously scrutinizes these nonlinear methods and their applications across the spectrum from modelling to rehabilitation. This mini-review aims to address this gap by highlighting recent advancements in nonlinear methodologies. These methodologies have demonstrated the potential to enhance the efficacy of interventions for individuals with sit-to-stand disorders, encompassing the design of intelligent rehabilitation devices, mitigating fall risks, and facilitating early patient classification.
Keywords: Sit to stand, Nonlinear, Rehabilitation, Biomechanics.

Cite this article as:
Torbati, A. H. M., & Davoudi, N. (2024). Nonlinearity analysis of sit-to-stand and its application: A mini-review. *Scientific Journal of Sport and Performance*, *3*(2), 180-187. https://doi.org/10.55860/RWEX2284

Corresponding author. *Department of Advanced Biomedical Sciences. University of Naples "Federico II". Naples, Italy.*
E-mail: hakakarmin@gmail.com
Submitted for publication January 07, 2024.
Accepted for publication February 07, 2024.
Published March 03, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/RWEX2284

INTRODUCTION

The study of human biomechanics has been ongoing for numerous years (Zinkovsky et al. 1996). By employing mathematical models of the musculoskeletal structure of humans, motion analysis is conducted to enhance comprehension and refine the mechanisms of body movement. The examination of biomechanics encompasses three primary categories: sit-to-stand transitions, postural control, and gait. Among these activities, the sit-to-stand transition stands out as one of the most intricate and frequently performed tasks in an individual's daily life (Janssen et al. 2002). For instance, a physically well individual typically engages in around 65 sit-to-stand movements on weekdays and 55 on non-working days (Dall and Kerr 2010). The sit-to-stand (STS) motion occurs through the coordination of physical elements, and the central nervous system (CNS) issues movement commands based on feedback received from muscles and vestibular sensors (Matthis and Fajen 2013). The STS activity comprises four phases: (1) the flexion momentum phase, involving the rotation of the upper body, shifting the centre of mass (CoM) forward and slightly downward; (2) the transition phase between horizontal and vertical momentum; (3) the extension phase, during which the vertical component of the CoM ascends; and (4) the finalization of motion with stabilization. The most challenging moment during the sit-to-stand task occurs when the body loses contact with the chair. At this point, the posture is typically statically unbalanced, with the centre of mass (CoM) positioned behind the wheel and outside the support region (Riley et al. 1991, Gross et al. 1998).

Rising from a seated position is a crucial requirement for preserving an individual's stability by placing the vertical component of the reaction force within the support area (Rodosky et al. 1989). This action is fundamental not only for walking but also for ensuring the functional independence of the person (Lord et al. 2002, Dehail et al. 2007). There have also been reports indicating that individuals facing challenges in transitioning from a seated position to standing are at a higher risk of instability and falling while walking (Lord et al. 2002) or particularly at night when there is reduced assistance, individuals may encounter difficulties in maintaining stability when rising from bed or getting up from a chair(Bernardi et al. 2004). Especially among the elderly population, various physical issues arise, such as the gradual deterioration of muscle and cartilage tissues. These factors ultimately diminish an individual's capacity to execute the sit-to-stand movement. Furthermore, conditions like stroke, Parkinson's disease, and arthritis can significantly impair the ability to perform STS among patients (Nematollahi et al. 2019). Hence, comprehending the biomechanics of STS motion is essential for developing and evaluation techniques and rehabilitation devices (Torbati et al. 2022).

The motor control of human activities, such as the sit-to-stand motion, has proven to be a difficult task for scientists and engineers. This is due to its distributed, nonlinear, and time-varying nature, characterized by numerous degrees of freedom and redundancy at various levels. So managing and modifying this system has presented significant challenges for researchers and engineers alike. Conventional biomechanical assessments of human movement typically rely on linear mathematical approaches. While these methods may be advantageous in various scenarios, they often fall short of accurately capturing the predominantly nonlinear characteristics inherent in human systems. Consequently, nonlinear analytical techniques grounded in a dynamical systems approach have gained popularity in recent research. However, there is a noticeable absence of a comprehensive review paper that scrutinizes these methods and applications ranging from modelling to rehabilitation.

REHABILITATION

Repeatedly moving the knees can result in the deterioration of knee function for a generally healthy elderly person. Additionally, individuals with weak knees or those dealing with chronic conditions or disabilities may experience even more pronounced effects from repetitive knee movements, especially in the context of STS motion (Heidari 2011).

Modelling for rehabilitation

As previously stated, creating a STS model serves as the initial phase in developing a rehabilitation device. Simultaneously, achieving a typical STS transition necessitates synchronization between the upper and lower body movements. To elucidate the coordination dynamics inherent in a standard STS motion, it is crucial to employ a suitable model. This model plays a pivotal role in devising control and assessment techniques essential for the design of intelligent rehabilitation devices (Torbati et al. 2022). Another crucial aspect is the validation of the proposed model. A primary method involves employing the nonlinear features of the model alongside experimental data, a practice endorsed in previous studies (Nasim et al. 2021) and applied in recent years (Torbati et al. 2022). This is due to the effectiveness of the concept of dynamic similarity in establishing a suitable framework for interpreting the parallels and distinctions in locomotion. Hakkak and colleagues employed a Henon map optimized through a Genetic algorithm to develop a STS model and then proved its performance was subsequently validated by comparing extracted nonlinear features from the phase space, including the Lyapunov exponent (LE), and correlation dimension (CD) (Torbati et al. 2022). Creating a model based on experimental data sometimes can be challenging, prompting the presentation of a virtual nonlinear predictive model. This model was introduced and then contrasted with recorded data from subjects, with a focus on utilizing peak values of kinematic and kinetic results for the comparison. This model incorporates recursive Lagrangian dynamics and an optimization formulation. Its versatility extends to applications in designing exoskeletons, microelectromechanical systems for fall detection, and assistive devices in rehabilitation (Yang and Ozsoy 2020). In alternative models, researchers integrated various controllers into their nonlinear models to estimate true states. This adaptation aimed to address challenges such as noise, delays in neurofeedback from the central nervous system, and disturbances. In more detail, Linear Quadratic Regulator (LQR) and H based compensator is employed to mitigate the noise, and delay in neurofeedback of CNS and achieve natural motion (Rafique et al. 2018, Rafique et al. 2019). In addition to this, a Lyapunov-based controller was used in a linkage-based dynamic model of STS motion extracted using Lagrange's equation in the presence of sinusoidal bounded disturbances to track the desired trajectory acquired from experimental kinematic data (Nematollahi et al. 2019). In two separate studies, a nonlinear control technique grounded in feedback linearization was employed to replicate the control actions of the central nervous system during the execution of STS movements (Sultan et al. 2018, Sultan et al. 2021).

Enhancing the operational efficiency of Functional Electrical Stimulation (FES)-induced STS movements is a challenge currently under scrutiny by numerous scholars in the field. When employing FES, there are two fundamental control schemes: linear and nonlinear control methods. Research has demonstrated that the performance of the feedback linearization control (FLC) method surpasses that of the Proportional-Integral-Derivative (PID) control technique by a significant margin (Ahmed et al. 2019). So nonlinear controller is much better than linear ones for FES. Among three nonlinear controllers—Sliding Mode Control (SMC), Feedback Linearized Control (FLC), and Back Stepping Control Approach (BSC)—all schemes demonstrated strong performance. The Back Stepping Control Approach stood out as the best, exhibiting the highest Robustness to Disturbance Rejection (RDR), followed by FLC and then SMC (Ahmed et al. 2022).

Robot assistant for rehabilitation

One of important STS rehabilitation techniques is to use assistant robots, aiming to effectively help individuals stand up from a seated position using a robot manipulator. A up to dated method is proposed by Li et al. The proposed method integrates traditional model-based control, optimization, and AI-based human intention recognition. The approach involves recording human-to-human STS assistance demonstrations, extracting

 © 2024 ARD Asociación Española

average intended motion trajectories for lower limb joints, and generating an optimal robot end-effector trajectory offline to minimize human joint loads. To adapt to variations in human motion, a Long Short-Term Memory (LSTM) network predicts changing intentions during STS assistance, adjusting the robot's velocity accordingly. Simulations and experiments demonstrate the algorithm's ability to minimize joint loads while following the user's intention, making it potentially applicable to home robots assisting elderly and disabled individuals in daily activities (Li et al. 2021).

Facilitation of Assistive STS Motion

Those providing assistance for STS encounter challenges, particularly in experiencing lower back pain (LBP) during the supportive movements for STS. Past research suggests that modifying the position of the feet can alleviate the lumbar load in such situations. To tackle this issue, a novel approach was suggested, involving the quantitative measurement of foot position during the STS process through the use of wearable sensors. This technique utilizes machine learning, incorporating features extracted from a solitary inertial sensor positioned on the trunk, along with shoe-type force sensors. The experimental findings indicate that the suggested approach exhibits a notable level of accuracy when compared to an optical motion capture system. Consequently, this method holds promise for measuring foot position during the supportive movements of STS, potentially leading to a reduction in LBP among caregivers (Kitagawa et al. 2021).

DETERMINATION OF FALL RISK

Emphasizing the importance of discerning the intention to prevent falls, rather than solely focusing on detecting the fall event itself, has been underscored as a critical element. This emphasis facilitates the development and deployment of intelligent devices and techniques that offer reliable support (Doulah et al. 2016). Even with the implementation of best practices in hospitals, the incidence of falls remains elevated, prompting an exploration of technological solutions to address this persistent challenge. Recent progress in addressing falls includes the application of camera surveillance and pressure sensors to identify high-risk body movements. However, it's worth noting that these approaches bring along computational complexities, latency issues, and privacy concerns. A promising alternative is found in wearable sensing devices such as inertial measurement units and accelerometers. This choice is appealing due to its cost-effectiveness, user-friendly nature, and capacity to furnish valuable information for deducing physical activities. Significantly, Sit-to-Stand (Si to St) and Stand-to-Sit (St to Si) activities have been focal points in various studies, utilizing these movements as key indicators to assess the risk of falls in older individuals (Capela et al. 2015, Ejupi et al. 2016, Pozaic et al. 2016). Furthermore, the application of technology extends to predicting fall risk in the elderly, with a specific focus on nonlinear analysis (Nasim et al. 2021). It is proven that nonlinear recurrence features for STS (Nasim et al. 2021) and virtual modelling based on recursive Lagrangian dynamics, and the optimization formulation(Yang and Ozsoy 2020) have acceptable performance for this issue.

STABILITY

In recent years, researchers have been increasingly drawing inspiration from biological systems and their self-stabilization mechanisms to design robots or robotic structures that need to uphold stability. By employing LE, computed based on experimental time series data collected for all six joints, it becomes possible to quantify the local dynamic stability of human lower limb joints during STS movements (Gibbons et al. 2019, Tarnita et al. 2021).

CLASSIFICATION

Early diagnosis plays a pivotal role in the successful treatment and mitigation of side effects for patients grappling with various diseases. The significance of timely identification cannot be overstated, as it not only enables prompt medical intervention but also enhances the overall prognosis and quality of life for individuals facing health challenges. Nonlinear analysis proves valuable in classifying patients with motor control disorders. For instance, the use of Approximate Entropy (ApEn) reveals that Parkinson's disease (PD) patients exhibit larger ApEn values compared to healthy individuals. Additionally, for PD patients, transitioning from the deep brain stimulation (DBS) off-state to the DBS on-state results in a decrease in ApEn values. Indeed, Parkinson's disease leads to an increase in the irregularity of both stand-to-sit and sit-to-stand patterns. However, the implementation of deep brain stimulation (DBS) results in a decrease in the irregularity of these patterns, rendering them more predictable (Fatmehsari and Bahrami 2011). Additionally, the classification of patients can also be achieved by assessing stability through LE (Tarnita et al. 2021).

CONCLUSION

The exploration of human biomechanics, with a specific focus on the intricate STS motion, has revealed its paramount importance in maintaining stability, functional independence, and fall prevention, especially among the elderly and those with specific health challenges. The multifaceted nature of STS motion has been dissected into phases, revealing the challenges posed during the transition from a seated to a standing position. This comprehensive understanding has paved the way for innovative approaches in rehabilitation, including the development of models, controllers, and robotic assistants. The integration of nonlinear analytical techniques, such as dynamic similarity assessments and the application of various controllers, has proven instrumental in enhancing rehabilitation strategies. The use of wearable sensors and inertial measurement units for fall risk determination offers a promising alternative to traditional methods, with a particular emphasis on nonlinear analysis. Drawing inspiration from biological systems, researchers have explored stability through LE, contributing to the design of self-stabilizing robotic structures. Furthermore, nonlinear analysis, including ApEn, has demonstrated its efficacy in classifying patients with motor control disorders, offering valuable insights for early diagnosis and improved treatment outcomes. Despite the challenges posed by the distributed and nonlinear nature of human activities, the ongoing research in biomechanics continues to unveil novel approaches that hold great promise for the development of effective rehabilitation techniques and intelligent devices. Nevertheless, the number of studies in this field is limited and needs more attention in the future.

AUTHOR CONTRIBUTIONS

All the authors have contributed equally to each of the sections of the study conducted.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

© 2024 ARD Asociación Española

REFERENCES

Ahmed, M., M. Huq, B. Ibrahim, S. A. Jalo and G. Elhassan (2019). Evaluating the Linearized Feedback Controller for Regulation of Aided Sit-to-Stand in Subjects with Spinal Cord Injuries. 2019 IEEE 7th Conference on Systems, Process and Control (ICSPC), IEEE. https://doi.org/10.1109/ICSPC47137.2019.9068085

Ahmed, M., M. Huq, B. Ibrahim, N. M. Tahir, Z. Ahmed and G. Elhassan (2022). A Comparative Study on Nonlinear Control of Induced Sit-to-Stand in Paraplegia with Human Mass Variation. Recent Trends in Mechatronics Towards Industry 4.0: Selected Articles from iM3F 2020, Malaysia, Springer.

Bernardi, M., A. Rosponi, V. Castellano, A. Rodio, M. Traballesi, A. S. Delussu and M. Marchetti (2004). "Determinants of sit-to-stand capability in the motor impaired elderly." Journal of Electromyography and kinesiology 14(3): 401-410. https://doi.org/10.1016/j.jelekin.2003.09.001

Capela, N. A., E. D. Lemaire and N. Baddour (2015). Improving classification of sit, stand, and lie in a smartphone human activity recognition system. 2015 IEEE International Symposium on Medical Measurements and Applications (MeMeA) Proceedings, IEEE. https://doi.org/10.1109/MeMeA.2015.7145250

Dall, P. M. and A. Kerr (2010). "Frequency of the sit to stand task: an observational study of free-living adults." Applied ergonomics 41(1): 58-61. https://doi.org/10.1016/j.apergo.2009.04.005

Dehail, P., E. Bestaven, F. Muller, A. Mallet, B. Robert, I. Bourdel-Marchasson and J. Petit (2007). "Kinematic and electromyographic analysis of rising from a chair during a "Sit-to-Walk" task in elderly subjects: role of strength." Clinical Biomechanics 22(10): 1096-1103. https://doi.org/10.1016/j.clinbiomech.2007.07.015

Doulah, A., X. Shen and E. Sazonov (2016). "A method for early detection of the initiation of sit-to-stand posture transitions." Physiological measurement 37(4): 515. https://doi.org/10.1088/0967-3334/37/4/515

Ejupi, A., M. Brodie, S. R. Lord, J. Annegarn, S. J. Redmond and K. Delbaere (2016). "Wavelet-based sit-to-stand detection and assessment of fall risk in older people using a wearable pendant device." IEEE Transactions on Biomedical Engineering 64(7): 1602-1607. https://doi.org/10.1109/TBME.2016.2614230

Fatmehsari, Y. R. and F. Bahrami (2011). Sit-to-stand or stand-to-sit: Which movement can classify better Parkinsonian patients from healthy elderly subjects? 2011 18th Iranian Conference of Biomedical Engineering (ICBME), IEEE. https://doi.org/10.1109/ICBME.2011.6168583

Gibbons, C. T., P. G. Amazeen and J. J. Jondac (2019). "Thinking on your feet: An analysis of movement and cognition in a sit to stand task." Acta psychologica 192: 52-58. https://doi.org/10.1016/j.actpsy.2018.10.014

Gross, M., P. Stevenson, S. Charette, G. Pyka and R. Marcus (1998). "Effect of muscle strength and movement speed on the biomechanics of rising from a chair in healthy elderly and young women." Gait & posture 8(3): 175-185. https://doi.org/10.1016/S0966-6362(98)00033-2

Heidari, B. (2011). "Knee osteoarthritis prevalence, risk factors, pathogenesis and features: Part I." Caspian journal of internal medicine 2(2): 205.

Janssen, W. G., H. B. Bussmann and H. J. Stam (2002). "Determinants of the sit-to-stand movement: a review." Physical therapy 82(9): 866-879. https://doi.org/10.1093/ptj/82.9.866

Kitagawa, K., I. Gorordo Fernandez, T. Nagasaki, S. Nakano, M. Hida, S. Okamatsu and C. Wada (2021). "Foot Position Measurement during Assistive Motion for Sit-to-Stand Using a Single Inertial Sensor and Shoe-Type Force Sensors." International Journal of Environmental Research and Public Health 18(19): 10481. https://doi.org/10.3390/ijerph181910481

Li, J., L. Lu, L. Zhao, C. Wang and J. Li (2021). "An integrated approach for robotic Sit-To-Stand assistance: Control framework design and human intention recognition." Control Engineering Practice 107: 104680. https://doi.org/10.1016/j.conengprac.2020.104680

Lord, S. R., S. M. Murray, K. Chapman, B. Munro and A. Tiedemann (2002). "Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people." The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 57(8): M539-M543. https://doi.org/10.1093/gerona/57.8.M539

Matthis, J. S. and B. R. Fajen (2013). "Humans exploit the biomechanics of bipedal gait during visually guided walking over complex terrain." Proceedings of the Royal Society B: Biological Sciences 280(1762): 20130700. https://doi.org/10.1098/rspb.2013.0700

Nasim, A., D. C. Nchekwube and Y. S. Kim (2021). "Reliability of Recurrence Quantification Analysis Measures for Sit-to-Stand and Stand-to-Sit Activities in Healthy Older Adults Using Wearable Sensors." Electronics 10(19): 2438. https://doi.org/10.3390/electronics10192438

Nematollahi, M. H., S. A. Haghpanah and S. Taghvaei (2019). "Inverse Dynamic Robust Control of Sit-to-Stand Movement." Biomedical Engineering: Applications, Basis and Communications 31(06): 1950041. https://doi.org/10.4015/S1016237219500418

Pozaic, T., U. Lindemann, A.-K. Grebe and W. Stork (2016). "Sit-to-stand transition reveals acute fall risk in activities of daily living." IEEE journal of translational engineering in health and medicine 4: 1-11. https://doi.org/10.1109/JTEHM.2016.2620177

Rafique, S., A. Mahmood and M. Najam-ul-Islam (2018). Robust control of physiologically relevant sit-to-stand motion using reduced order measurements. Proceedings of the Future Technologies Conference, Springer. https://doi.org/10.1007/978-3-030-02683-7_56

Rafique, S., M. Najam-I-Islam and A. Mahmood (2019). Synthesis of sit-to-stand movement using SimMechanics. International Conference on Smart Innovation, Ergonomics and Applied Human Factors, Springer. https://doi.org/10.1007/978-3-030-22964-1_43

Riley, P. O., M. L. Schenkman, R. W. Mann and W. A. Hodge (1991). "Mechanics of a constrained chair-rise." Journal of biomechanics 24(1): 77-85. https://doi.org/10.1016/0021-9290(91)90328-K

Rodosky, M. W., T. P. Andriacchi and G. B. Andersson (1989). "The influence of chair height on lower limb mechanics during rising." Journal of Orthopaedic Research 7(2): 266-271. https://doi.org/10.1002/jor.1100070215

Sultan, N., A. M. Mughal, M. N. u. Islam and F. M. Malik (2021). "High-gain observer-based nonlinear control scheme for biomechanical sit to stand movement in the presence of sensory feedback delays." Plos one 16(8): e0256049. https://doi.org/10.1371/journal.pone.0256049

Sultan, N., M. Najam-ul-Islam and A. Mahmood (2018). Nonlinear control synthesis of biomechanical sit to stand movement. 2018 22nd International Conference on System Theory, Control and Computing (ICSTCC), IEEE. https://doi.org/10.1109/ICSTCC.2018.8540659

Tarnita, D., A. Petcu, M. Georgescu, I. Geonea and D. Tarnita (2021). Nonlinear Dynamic Analysis of Human Sit-to-Stand Movement with Application to the Robotic Structures. New Trends in Medical and Service Robotics: MESROB 2020 7, Springer. https://doi.org/10.1007/978-3-030-58104-6_27

Torbati, A. H. M., S. Jami and H. R. Kobravi (2022). "Is the Hénon map able to predict the interaction dynamics between the knee and hip joints emerged during sit-to-stand movement?" Biomedical Physics & Engineering Express 8(4): 045003. https://doi.org/10.1088/2057-1976/ac6caa

Yang, J. and B. Ozsoy (2020). "Three dimensional unassisted sit-to-stand prediction for virtual healthy young and elderly individuals." Multibody System Dynamics 49: 33-52. https://doi.org/10.1007/s11044-019-09699-9

Zinkovsky, A. V., V. A. Sholuha and A. A. Ivanov (1996). Mathematical modelling and computer simulation of biomechanical systems, World Scientific. https://doi.org/10.1142/9789812796967

 © 2024 ARD Asociación Española

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

REVIEW ARTICLE

Home advantage and the influence of officiating decisions: A current review of the literature and strategies for reducing referee bias

Simcha Avugos . *School of Human Movement and Sport Sciences. Academic Center Levinsky-Wingate – Wingate Campus. Wingate Institute. Netanya, Israel.*

ABSTRACT

Even after decades of research, it is largely unclear how the various factors that cause the home advantage act and interact with one another. This paper provides an updated narrative review of the home advantage in sports, with a particular interest in the impact of refereeing. We used multiple sources for data collection and limited our search to peer-reviewed journals. Detailed information was extracted and documented from each of the retrieved articles. Bibliometric data were also calculated and assessed to evaluate the evolution of research in this field. The findings of this review show that home advantage is elevated in certain type of sports and due to properties of the crowd. In particular, the social pressure of the home crowds has direct and indirect effects on both home advantage and referee bias. Studies on games played in empty stadiums provided significant evidence for a reduced referee bias, and a decline in athlete-related variables. Several potential directions for future research emerged from this review. More research on the home advantage in women's sports, in individual sports, and at lower levels of play is warranted. These efforts will contribute to further extend our understanding of this fascinating phenomenon.

Keywords: Home advantage, Referee bias, Sport performance, Crowd effects, Officiating decisions.

Cite this article as:
Avugos, S. (2024). Home advantage and the influence of officiating decisions: A current review of the literature and strategies for reducing referee bias. *Scientific Journal of Sport and Performance*, *3*(2), 188-219. https://doi.org/10.55860/DUBO8273

Corresponding author. *School of Human Movement and Sport Sciences, Academic Center Levinsky-Wingate – Wingate Campus, Wingate Institute, Netanya 4290200, Israel.*
E-mail: avugos@gmail.com
Submitted for publication January 09, 2024.
Accepted for publication February 07, 2024.
Published March 03, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/DUBO8273

INTRODUCTION

Officials play an important role in most competitive sports. Over the past two decades, research on sports officiating has greatly increased, covering a range of aspects relating to the officials' development, training, and performance. Notably, an expanding body of research has focused on the judgment and decision making of sport officials (e.g. Helsen et al., 2019; Raab et al., 2020; Samuel et al., 2021), due to the potential impact of their decisions on match outcomes.

While officials are expected to avoid making erroneous decisions, it is inevitable that mistakes occur. Errors can arise from internal factors related to the competitors and the referees themselves, as well as external situational factors (Plessner & Haar, 2006). These sources of error include individual heuristics, limited information, contextual influences, emotional factors, time pressure, and cognitive load. Research has extensively addressed issues of visibility, such as referees' on-field positioning, and visual perceptions, such as attention and distracting cues, and how these factors contribute to referee errors (e.g. Hüttermann et al., 2018; Spitz et al., 2016). In some sports, being in an optimal position or being able to move to the best position is of the utmost importance when picking up on information about the actual situation (e.g. offside judgments in soccer; Oudejans et al., 2000).

Biased referee judgments could also stem from various factors, including the reputation, nationality, physical appearance, uniform colour, and stereotyping of athletes or teams (e.g. McCarrick et al., 2020; Price & Wolfers, 2010; Souchon et al., 2009; Stone et al., 1997). Other documented bias-based decisions were impacted by the current status of the match, with favouritism being shown towards the more successful team (e.g. Erikstad & Johansen, 2020; Lago-Peñas & Gómez-López, 2016). Even prior decisions made by referees could impact their subsequent decisions in a game – as they attempt to convey consistency in their enforcing of the rules and ensure the flow of the game (Unkelbach & Memmert, 2008).

This literature review focuses on a specific type of referee bias known as *home bias*, which is proved to be one of the main causes of the home advantage (HA). The HA is the consistent and robust phenomenon in sports whereby the home team or athlete wins more often (> 50%) than the visiting opponent when competing in their home ground (Courneya & Carron, 1992; Pollard, 1986, 2008)[1]. An early publication from one hundred years ago (Luehring, 1923) suggested that officials were biased towards the home team when officiating a match between basketball teams from the east and west of the United States. The pioneering paper by Schwartz & Barsky (1977) further confirmed the existence of HA in organized sports, attributing it to factors such as travel, familiarity with the playing field, and the presence of home fans. Subsequent studies across various sports and a recently published book by Gómez-Ruano et al. (2021) have provided extensive evidence on the HA effect, exploring its causes and impact on performance.

This study offers a useful summary of a research area that has recently received increasing attention, in light of the COVID-19 pandemic that rendered numerous sport events to take place behind closed doors (e.g. Alonso et al., 2022; Bryson et al., 2021; Endrich & Gesche, 2020; Fischer & Haucap, 2021; Gong, 2022; Sors et al., 2023). Expanding on recent reviews (Dohmen & Sauermann, 2016: biased behaviour of sports referees; Leitner et al., 2022: the HA in soccer during ghost games in the 2020-2021 season; also see the Introduction by Reade et al., 2022), this paper further refines and extends that existing knowledge in a number of ways. First, this review provides an extensive and updated overview of the literature on the HA in general,

[1] *Home advantage should not be confused with home performance. In order to be of relevance to HA, home performance has to be compared with away performance.*

and about referee bias in particular, spanning almost five decades of research (1977-2022) and a range of sports. As such, the study addresses the still-emerging literature stream regarding the impact of empty stadiums on refereeing decisions during the COVID pandemic, pulling all scientific published papers throughout the entire period. In addition, it incorporates concise bibliometric information to trace the evolution of research in this field and its resulting outputs. Second, this review draws the attention to the perspectives of key stakeholders involved in this phenomenon, an aspect largely overlooked in existing literature, which may affect the formation and degree of the HA. Third, drawing upon the classical conceptual framework initially introduced by Courneya and Carron (1992), and later refined by Pollard (2008), the study proposes a modified version of the HA model that accounts for both the direct and indirect effects of the crowd through its influence on sports officials (see Figure 2). Finally, the study discusses strategies for reducing referee bias to improve the quality of decisions and outlines possible paths for future research.

METHODS

Approach to secondary research

Previous reviews on the HA used a rigorous and systematic methodology, mainly aiming to minimize reviewer bias. However, recent critiques have challenged the traditional hierarchy, questioning the superiority of systematic reviews over unsystematic or narrative reviews (e.g. Collins & Fauser, 2005; Greenhalgh, 2012; Greenhalgh et al., 2018). Calls have been made to strike a balance between these two typical review types, leveraging the strengths of each approach.

In line with these contemporary perspectives, this study applied a narrative synthesis approach to consolidate previously published information. Since no strict published guidelines prescribe precisely what should or should not be included in a quality narrative overview, we have followed recommendations that are generally acceptable in many journals (e.g., Green et al., 2006).

Data sources and search strategy

We searched the databases Web of Science (WOS), SPORT Discus, and Google Scholar using the key terms *home advantage* and *referee bias*. These databases are widely recognized as comprehensive bibliographic data sources in the social sciences and sports. In order to ensure inclusiveness, we considered various denominations of the HA construct, such as home field, home court, home team, home ground, and home site advantage. These terms were combined with specific queries related to sports, including team sports, sport performance, performance analysis, and decision making. The search was conducted within the title, abstract, and keywords of the articles indexed. We collected studies available in these databases up until October 2022, which served as the cutoff date for data retrieval for this review. References lists of the obtained articles were searched by hand.

Eligibility criteria

For this review, we exclusively included original studies published in peer-reviewed journals due to their adherence to scientific rigor and credibility standards. We excluded articles with incomplete full-text availability, those not written in English, and those classified as grey literature. Dissertations were also excluded from consideration, as many of them are subsequently published in journals. Additionally, we removed studies that were not relevant to the focused purpose of the present study (e.g. Fuxjager et al., 2009: winner effects and hormone changes).

After several rounds of manual screening and duplicate checks, a total of 426 articles were deemed suitable for review. Most of these articles involved empirical investigations of the phenomenon, while a few were

 © 2024 ARD Asociación Española

purely descriptive. To ensure consistency, the same reviewer (the author of this article) re-evaluated the selected articles a few weeks later, establishing intra-rater reliability.

Clearly, not all articles could be cited due to their sheer quantity. However, to ensure citation breadth, we have cited a comprehensive range of literature (158 items), and the studies cited are representative of those available.

Data extraction
We read through each of the retrieved articles and noted down their basic information (year, authorship, journal) and the following specific details pertaining to their properties: study's objectives, research design or methods employed, type of sport (individual vs. team sport), specific sport, analysed league(s), level of competition (e.g. professional, collegiate), analysed factors (e.g. win ratio, goals, fouls, cards), statistics used, and key findings and conclusions. We used Excel spreadsheets to collect the data extracted from each paper reviewed.

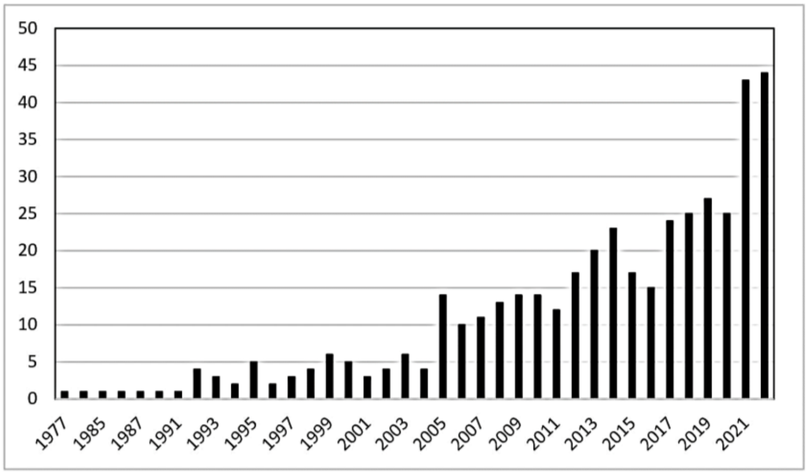
RESULTS

Our dataset shows that studies have been conducted in 16 different team sports and about twice that number of individual sports, including the Olympic summer and winter sports. Several studies used data from multiple sports (e.g. Gómez et al., 2011; Pollard, 2002). Notably, soccer emerged as one of the most extensively researched sports, accounting for about 50% of the studies, likely attributed to the popularity of men's soccer globally. In contrast, only 18 studies in our dataset examined the HA in women's sports, some of which compared women's and men's leagues.

Our review develops as follows: we start with the description of some bibliometric data. Then, we review the literature on the HA in competitive sports and its causes. Finally, we present the research findings on the crowd effects and referee bias.

Bibliometric characteristics
Our final dataset comprised 426 papers authored by 207 researchers, affiliated with 206 institutions, and from 49 countries/regions. The countries of the corresponding authors with the highest number of articles were the United States (107), England (89), Spain (63), Australia (41), and Germany (34). Brazil, Canada, and Portugal follow these countries with over 20 publications each. Of these 426 papers, 16 were published during 1977-1994, 25 during 1995-2000, 93 during 2001-2010, and 205 during 2011-2020. In addition, 87 articles were published or assigned to an issue during 2021-2022, mainly on matches held without spectators following the outbreak of the COVID-19 pandemic in early 2020.

The distribution of publications by year is displayed in Figure 1, and it reflects the evolution of production in this field over the past 46 years (Prieto, 2021). The graph shows the growing interest in HA research, especially since 2005. In April 2005, the *Journal of Sports Sciences* published a special issue on the HA, featuring articles from leading authors in the field. Since then, several reviews and meta-analyses have contributed to the literature (e.g. Jamieson, 2010; Pollard, 2006, 2008). A considerably small number of articles were published prior to 1995, with the following distribution: two in 1994, three in 1993, four in 1992, one in 1991, one in 1990, one in 1987, one in 1986, one in 1985, one in 1983, and one in 1977.



Note: Records for the year 2022 are up until October, when this review was conducted.

Figure 1. Distribution of home advantage publications by year.

The 426 articles were published in 129 different journals. The top five most active journals in HA research include the *Journal of Sports Sciences* (43 published articles; IF=3.943)[2], *International Journal of Performance Analysis in Sport* (40; IF=2.488), *Journal of Sports Economics* (25; IF=1.848), *Perceptual and Motor Skills* (25; IF=2.212), and *Psychology of Sport and Exercise* (15; IF=5.118), having published 34.7% of the total number of articles in the current analysis. Among the authors, the five most productive authors include Gómez (28 articles), Pollard (25), Nevill (15), Lago-Peñas (12), and Sampaio (11). In terms of citation impact, the five most cited papers throughout the analysed period include Courneya and Carron (1992), Nevill et al. (2002), Nevill and Holder (1999), Lago-Peñas and Martín (2007), and Pollard (1986). These papers have received an average number of annual citations of 10.16, 13.95, 9.5, 14, and 5.84, respectively. The research areas in the HA field include sport sciences, social sciences, psychology, and business economics – which indicate a multidisciplinary approach to the study of the HA phenomena.

Evidence for HA in competitive sports

The vast majority of team sports follow a league format where teams meet twice, both at home and away. Unlike team sports, most events in individual sports are organized as tournaments, at fixed locations. This setup creates difficulties in comparing the performance of an athlete at home with performance under similar conditions away. Typically, home players belong to the country hosting the tournament, while the rest are considered away players. However, complexities arise when athletes change nationalities, further complicating the assessment. As a consequence, estimates of HA in individual sports are more involved and by far less researched compared to team sports.

The HA has been examined in various outdoor and indoor team sports, including American football, soccer, baseball, basketball, handball, volleyball, futsal, hockey, rugby, cricket, and water polo (e.g. Carron et al., 2005; Nevill & Holder, 1999; for sport-specific HA studies, see Gómez-Ruano et al., 2021), as well as the Summer and Winter Olympic sports (Balmer et al., 2001, 2003). While HA has consistently been found to impact points and goals (e.g. Ribeiro et al., 2016; Sors et al., 2021), it has also been observed in other performance-related variables, including ball possession, passes, tackles, distance covered, shooting attempts, and corner kicks (e.g. Lago-Peñas & Martín, 2007; Lago-Peñas et al., 2017). A recent study that

[2] *IF: 2021-2022 Journal Citation Reports (JCR) Impact Factor.*

 © 2024 ARD Asociación Española

compared the magnitude of the HA in a range of sports, for both genders and across countries, found evidence of this effect in all sports examined, yet with a greater effect observed in men's leagues than in women's (Pollard et al., 2017). Evidence from other studies suggest that HA tends to play a much smaller role in individual sports, such as golf, tennis, and boxing (Jones, 2013) and in one-on-one situations in team sports (e.g. ice-hockey shootouts) – with the exception of subjectively rated sports (e.g. diving, gymnastics, and figure skating; Balmer et al., 2003).

A meta-analysis by Jamieson (2010) examined the impact of several moderator variables on HA in 10 different sports. The analysis revealed a significant HA effect in all sports, however the magnitude of the effect varied depending on *era* (with greater HA observed before 1950), *season length* (with sports featuring over 100 games per season exhibiting a lower HA), *game type* (with high-pressure championships and playoff games showing a stronger HA effect), and *the sport itself* (with soccer demonstrating higher HA values and baseball showing lower HA values). Similar patterns were observed in an analysis of data from nine different professional team sports in Spain, further supporting the aforementioned findings (Gómez et al, 2011). However, rugby displayed the highest HA (67%), possibly due to the aggressive and intense nature of the sport.

In general, research shows that the home team or competitor wins about 60% of their contests, regardless of the level of competition (i.e. amateur, professional, or elite). For specific sports, home winning percentages were found to be about 55% for American Major League Baseball, 55-60% for ice hockey and American football, 60-65% for basketball and handball, and 60-70% for soccer (Carron et al., 2005; Pollard & Pollard, 2005). These figured indicate substantial differences in the odds.

The literature mostly examines the HA at the club level. Yet several studies have identified a highly significant and robust HA effect at the international level, such as World Cup matches and the Olympic games, with hosting nations achieving a higher number of wins or medals (Franchini & Takito, 2016). Variations in HA across different nations have been attributed to cultural and social characteristics (Gelade, 2015). For example, a particularly high HA has been identified within the Balkans, Andean nations of South America (such as Bolivia and Ecuador), and certain African countries (notably Nigeria, with an HA of almost 87%). This was also seen in games played by soccer teams from Corsica and Sicily – two ethnically distinct and isolated locations within their respective countries (Pollard, 2006; Pollard et al., 2017). Moreover, HA was significantly higher for teams playing in cities with a large ethnically distinct population and/or in geographically distinct parts of the country – in countries such as Bulgaria, Albania, Bosnia, Serbia, Turkey, and Greece (Armatas & Pollard, 2014). Differences in HA were also found in the Brazilian soccer league for teams playing in more isolated regions of the country. Finally, HA has also been associated with the city level, with a greater effect observed for teams playing in non-capital cities.

One possible explanation suggests that HA tends to be more prominent in countries characterized by high levels of collectivism and in-group favouritism. It is also higher in countries where the officials' integrity, such as the referees' normative values, and their adherence to rules and laws, including attitudes toward violence or corruption, are relatively low (Gelade, 2015; Sánchez & García-de-Alcaraz, 2021). Such explanation is consistent with the concept of HA as a social phenomenon, influenced by both the impact of the crowd on match officials and the sense of territoriality among players inhabiting these regions. It is plausible that such territoriality could be particularly pronounced in areas experiencing armed conflicts.

Causes of HA

Even after decades of research, the exact causes of HA are still debated. The literature points to six main factors, which can act independently or interact with one another: (1) crowd effects (e.g. Salminen, 1993); (2) the adverse effects of travel, including fatigue, changes in time zones or climate (e.g. Pace & Carron, 1992); (3) territoriality, i.e. a feeling of ownership, and the territorial protective response to the invasion of rivals – as part of the social bonding when competing at home (Neave & Wolfson, 2003); (4) familiarity with the local facility, such as the stadium architecture (Pollard, 2002) or playing surfaces (van Ours, 2019); (5) rules of the sport that directly or indirectly favour the home team or athlete (relevant in a limited number of sports; e.g. the advantage of batting last in baseball; Courneya & Carron, 1990); and (6) referee bias, including disciplinary sanctions used and points decisions (e.g. Balmer et al., 2005; Dohmen & Sauermann, 2016). HA can also be the result of different tactics and playing styles, such as teams who display more effective offensive actions (rather than defensive ones), quicker attacks, and more collective tactical behaviour among the home players (Staufenbiel et al., 2015).

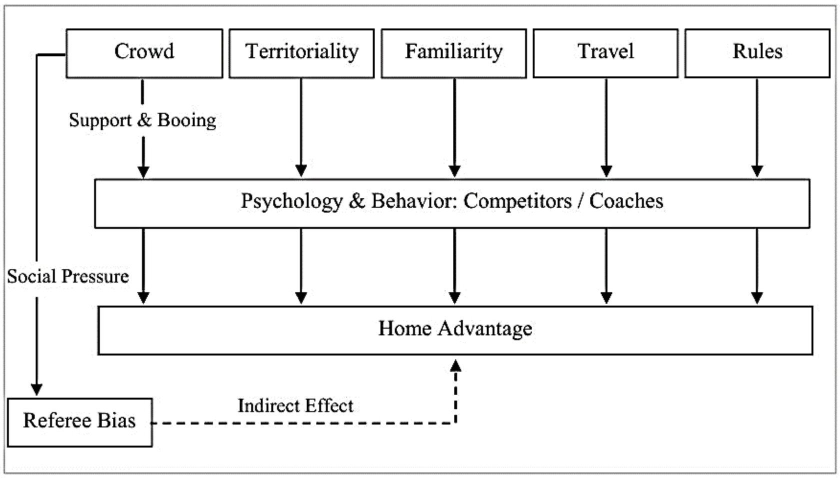
The HA is commonly explained through three main frameworks, each outlining factors that impact the psychological, behavioural, and physiological states of the athletes, coaches, and officials (Carron et al., 2005; Courneya & Carron, 1992; Dosseville et al., 2016; Pollard, 2008; for a review see Allen & Jones, 2014). These changes, in turn, impact performance outcomes. Courneya and Carron (1992) were the first to introduce a conceptual HA model, drawing upon theories from several fields, including biology (e.g. territoriality of local players with increased testosterone levels), psychology (e.g. the impact of arousal and anxiety on both local and visiting players), cognition (e.g. increased assertiveness among local players), and sociology (e.g. social support for local players' behaviour). A later revision of this model removed the term *officials*, as they were deemed to lack a home or away status (Carron et al., 2005).

The possible sources of HA differ across competitions and teams. Specifically, travel factors are not so relevant in most individual sports due to tournaments being held in fixed locations. In addition, familiarity with local conditions may be helpful in some specific cases than in other cases, such as a tennis player's familiarity with a particular playing surface. Rule-related advantages may also apply selectively, for example, seeding an athlete in the schedule. As for crowd noise or crowd support for athletes, although it may influence referees in many individual sports, as it happens in team sports, this is not the case in all sports. For example, golf audiences usually stand along the fairways of the holes, and typically applaud good strokes by both the home and visiting competitors. In addition, golf players are trusted to act fairly according to the rules, with the referees mainly having a consulting role in case of disagreement over a rules issue between players. One additional source of HA relevant to just individual sports is that, in some cases, home athletes may have better access to participation in tournaments than away athletes, on the basis of wild cards given to them by the tournament organization (Koning, 2011). These athletes from the home country have the opportunity to enter the competition although being not qualified to participate in the usual way.

As for team sports, since most sports use a league format in their competitions, travel effects (e.g. travel fatigue, sleep loss, or jet lag) are negligible when match site is a short distance away and within the same time zone (Courneya, & Carron, 1991). Some studies examining the effect of traveling across time zones did identify significant fluctuation in HA (e.g. Jehue et al., 1993). Overall, travel factors are not thought to be a major cause of the HA. In several sports, rule advantages and familiarity have been shown to be insignificant factors (Nevill & Holder, 1999), however not when teams have had to relocate to a new stadium (Pollard, 2002). In contrast, the evidence from studies investigating crowd factors appeared to provide the most dominant causes of HA. Two possible mechanisms were proposed to explain these observations. We will discuss the crowd effects, and the related referee bias, in more detail later.

 © 2024 ARD Asociación Española

Research on several team sports (e.g. Gómez et al., 2016; Yi et al., 2020) shows that match location (home/away) interacts with several other situational variables, such as the type of competition (e.g. regular season vs. knockout stage, playoffs, first leg vs. second leg), match status (i.e. the score-line: win/lose/draw, margins in the score), match period (e.g. first half vs. second half, set number), and quality of opposition (e.g. weak team vs. strong team). Other contextually influencing factors include match day, daytime, points earned in last matches, and the time elapsed since last match (Fischer & Haucap, 2021). Although these factors do not solely constitute the HA, they may add to its degree. Thus, investigating the complex interplay of causes of HA requires either a multivariate approach or careful control for possible confounding variables that are not among the main likely causes of the phenomenon, such as game importance or number of prior games played (Pollard, 2008).



Note: The model represents a modified version of Courneya and Carron's (1992) model, taking into account both the direct and indirect effects of the crowd on the home advantage and sports officials.

Figure 2. Conceptual framework of the home advantage and referee bias.

Dosseville et al. (2016) recently proposed a new HA framework that directly integrates the impact of sports officials, not solely thorough the influence of the crowd, but through four additional dimensions. These include *game situation*, which relates to factors that influence current decision making (e.g. the sport official's emotional state; Laborde et al., 2013); *expectations* that sports officials may develop towards teams (e.g. rank or reputation), crowd reaction (e.g. excited derbies or high match stakes), and the stadium (e.g. artificial playing field or the structural design of the stadium); *individual factors*, including individual differences in the official's personality, coping strategies, and emotional intelligence (Poolton et al., 2011), as well as differences in communications, social interactions, and player management (Avugos et al., 2021) – all of which could influence decision making processes and may have practical consequences; and *external pressures* that stem from ethical, cultural, and economic factors that should be considered when addressing the HA (e.g. a cultural closeness between the referee and the athlete or team, with regard to region or language; Torgler, 2004).

At the methodological level, the magnitude of HA in team sports has been quantified and compared in different sports, between teams or leagues, and over different time periods – at domestic or international level competitions. Studies commonly used simple outcome measures such as home winning percentage (calculated as the number of homes wins out of the number of total wins both at home and away), or in some sports the team's score difference (e.g. Courneya & Carron, 1992; Pollard & Pollard, 2005), known as the

Pollard method. For winning percentage, specific adjustments are needed for certain team sports, where games may end without a winner (e.g. soccer), and calculations may be based on the proportion of points won at home (Pollard, 1986).

Basic methods for quantifying HA (e.g. paired comparisons; Goumas, 2014) have been criticized for not addressing differences between the competing teams in a league or the situational variables that might affect the magnitude of the advantage, such as crowd size, venue size, and travel distance. Specifically, it is more likely for better quality teams to win games both at home and away, regardless of any home bias, as was found, for example, in the analysis of data from the English soccer league (Allen & Jones, 2014). To identify the true effect of HA, some studies have used different regression models that take into consideration various predictor variables (e.g. Armatas & Pollard, 2014).

In individual sports, estimates of HA are usually obtained through the analysis of either the relative performance (the probability that athlete *A* wins against athlete *B*; boxing: Balmer et al., 2005; tennis: Koning, 2011; judo: Krumer, 2017), absolute performance (e.g. finish time; skeleton: Chun & Park, 2021; biathlon: Harb-Wu & Krumer, 2019; speed skating: Koning, 2005), or medals won at the country level (e.g. combat sports; Franchini & Takito, 2016).

HA and referee bias: The crowd effect

As stated earlier, crowd factors appear to provide the most dominant causes of HA. However, there has been conflicting evidence as to how important crowd support is in contributing to HA. The crowd effect has been investigated in relation to noise (e.g. calm vs. pressing), size (attendance), density (percentage of ground capacity), and composition of the crowd (i.e. the balance between home and away supporters). For example, increased crowd noise due to the stadium architecture was found to be associated with greater HA effect in baseball and American football (Romanowich, 2012; Zeller & Jurkovac, 1989). Early studies investigated the impact of both crowd size and crowd density, yet only found evidence for either the impact of size (e.g. Pollard, 1986) or crowd density (e.g. Agnew & Carron, 1994), or that no such impact existed at all. However, according to a more recent study by Goumas (2014), it is crowd density that determines the HA and referee bias.

Boyko et al. (2007) found that crowd size (but not crowd density) and referee affected goal differential in the English Premier League, by affecting both home scoring and away scoring. It was also shown that larger crowds reduced the number of yellow and red cards given to the home team, and that crowd density negatively correlated with the number of away penalties. Conflicting evidence also exists regarding the impact of crowd composition on the results. The composition of the crowd is assumed to be influenced by the distance travelled by the visiting team, whereby the closer the home and away stadiums, the more likely the supporters of the away team are to travel to see their team play (Fontenla & Izón, 2018; Garicano et al., 2005).

Laboratory studies (e.g. Balmer et al., 2007; Nevill et al. 2002), as well as archival data (e.g. Balmer et al., 2001), were used to advance this line of research. It has even become possible to study the crowd effect in real-world settings, when teams have had to play home matches in empty stadiums – prior to the COVID crisis. For example, in the 2006-2007 season, tight safety regulations forced some teams in the Italian soccer league to play without spectators. Data on fouls, yellow cards, and red cards collected from 21 games played without spectators (out of 842 games that season) revealed a large and significant HA effect, whereby home teams were favoured in games *with spectators* compared to games *without spectators*, and whereby visiting teams were punished 20%-70% more harshly when crowds were present in the stadium (Pettersson-Lidbom

 © 2024 ARD Asociación Española

& Priks, 2010). However, player's performance (e.g. number of shots on target or number of tackles) does not seem to be affected by the presence or lack of spectators during games, for both home and away teams.

Further analysis of the same Italian league series of games showed that home crowd support is not a necessary precondition for HA, as the home team still had an advantage in games where no audience was present. Furthermore, in some same-stadium derbies (games played between 2 teams that share a stadium; e.g. AC Milan vs. Internazionale in soccer), the home team always has more crowd support (mainly thanks to season ticket holders; van de Ven, 2011), but in these games no HA existed. Sharing the same stadium by both teams from the same city cancels out the effect of travel fatigue and familiarity with the stadium. Yet when the study was replicated using twice the number of same-stadium derbies (128 observations), HA was seen, thereby suggesting that crowd noise does have an effect (Ponzo & Scoppa, 2018). Together, the current data show that crowd support contributes to the HA, but HA may still occur where no crowd is present. The phenomena might thus be much broader than assumed so far.

The global COVID-19 pandemic provided a semi-natural experiment to comprehensively test the effect of crowds on both referees and players. This has been possible due to a series of lockdowns and social distancing limitations that forced professional leagues around the world to play in empty stadiums (also known as "*ghost games*"). A literature review published by Leitner et al. (2022), when the pandemic was still raging, examined 20 peer-reviewed articles (out of 26) that were published up until April 2021 on soccer games without crowds. These studies vary in scope – ranging from an analysis of matches played in individual league or between leagues within the same country (e.g. Endrich & Gesche, 2020), to a number of leagues across countries (e.g. Benz & Lopez, 2021; Bryson et al., 2021). Almost all studies focused on European Leagues.

We extended Leitner et al.'s analysis to include an updated search, which yielded 61 peer-reviewed articles (5 in 2020; 28 in 2021; and 28 in 2022). The rich dataset contains studies in various team sports, including soccer (44), basketball (10), baseball (4), American football (2), rugby (3), and hockey (4), and involves teams with a range of abilities (see Table 1). The top four countries in the UEFA ranking (England, Germany, Italy, and Spain) stand out in the data, however data were also collected from North American leagues, Brazil, and Australia. The studies compared the HA, performance, and disciplinary aspects with or without crowds, and in few cases with partial attendance (games played with socially distanced fans under COVID-19 protocols; e.g. Ehrlich & Potter, 2023).

We found that most analysis has focused on the differences in wins, points, and goals scored for the home and away teams pre- and post-pandemic. However, other within-game performance indicators were also examined (e.g. Almeida & Leite, 2021; Bustamante-Sánchez et al., 2022; Link & Anzer, 2022), including team activity (e.g. running distance, number of sprints) and team performances (e.g. number of goal shots, corner kicks). About half of the studies on games played in empty stadiums (n=33) involve the analysis of referee's decisions regarding the number of warnings issued (e.g. fouls, penalties, yellow cards), send-offs (red cards), and extra time decisions. This proportion of referee-bias research is also observed in our overall dataset. Among the possible covariates examined by about third of the studies are players' experience, referee age and experience, team quality/strength, travel distance, days of rest before the match, altitude, daily weather, and stadium running track.

While the general trend seen in the data indicates slightly reduced HA during ghost games (yet with large differences between countries and competitions), more pronounced differences were seen in referee-related variables. For example, an analysis of 841 matches played by different national soccer leagues behind closed doors showed a slight decrease in the percentage of points and number of home victories, yet not for ball possession and corner kicks – and the absence of referee bias in terms of fouls, disciplinary cards, penalties, and recovery time given at the end of normal time (Sors et al., 2021). It seems that a certain degree of HA still exists even without spectators, due to the influence of other factors such as travel fatigue, familiarity with the pitch, and pre-match routines.

Table 1. Peer-reviewed studies on HA during the COVID-19 pandemic, by date.

No.	Year	Month	Author(s)	Sport	Data source/ Leagues/ Competition	Analysed factors (& possible covariates)
1	2020	Oct	Sánchez & Lavín	Soccer	Austria, England, Germany, Italy, Spain	Win ratio; Points; Goals; Budget; Stadium; Number of foreigners; Players' experience; Table position; Average attendance; Cards
2	2020	Nov	Tilp & Thaller	Soccer	Germany	Win ratio; Points; Goals; Table position; Fouls; Cards; Penalty kicks
3	2020	Nov	Sors et al.	Soccer	England, Germany, Italy, Spain	Win ratio; Points (Team strength); Goals; Ball possession; Shots; Shots on target; Corner kicks; Fouls; Cards; Penalty kicks; Extra time
4	2020	Dec	McHill & Chinoy	Basketball	NBA	Win ratio; Points; Shooting accuracy; Turnovers; Rebounds; Travel distance
5	2020	Dec	Endrich & Gesche	Soccer	Germany	Fouls; Yellow cards
6	2021	Jan	Bryson et al.	Soccer	Albania, Australia, Austria, Costa Rica, Denmark, England, Germany, Greece, Hungary, Italy, Poland, Portugal, Romania, Serbia, Slovenia, Spain, Ukraine	Win ratio; Goals; Cards
7	2021	Jan	Scoppa	Soccer	England, Germany, Italy, Portugal, Spain	Points (Team quality); Goals; Shots; Shots on target; Corner kicks; Days of rest before the match; Fouls; Cards; Penalty kicks
8	2021	Feb	Hegarty	Soccer	England, Germany, Italy, Spain; Asian Handicap market	Win ratio; Goals; Betting market pricing
9	2021	Feb	Winkelmann et al.	Soccer	Germany; Betting odds	Win ratio; Goals; Betting market pricing
10	2021	Mar	Santana et al.	Soccer	Germany	Win ratio; Goals; Goal attempts; Ball possession; Passes; Passes accuracy; Tackles; Corner kicks; Team distance covered; Sprints; Fouls; Offside
11	2021	Mar	Wunderlich et al.	Soccer	England, Germany, Italy, Portugal, Spain, Turkey	Points; Expected points; Goals; Shots; Shots on target; Betting odds; Fouls; Cards
12	2021	Mar	Almeida & Leite	Soccer	England, Germany, Italy, Portugal, Spain	Points; Goals; Shots; Shots on target; Ball possession; Passes; Aerial duels; Tackles; Cards
13	2021	Apr	Matos et al.	Soccer	Portugal	Points
14	2021	Apr	Hill & Van Yperen	Soccer	England, Germany, Italy, Spain	Points; Goals; Shots; Ball possession; Fouls; Cards
15	2021	May	Zimmer et al.	Baseball	MLB	Win ratio; Extra innings; Runs per game; Daytime
16	2021	Jun	Ferraresi & Gucciardi	Soccer	England, France, Germany, Italy, Spain	Scored and unscored penalties; Attendance

 © 2024 ARD Asociación Española

17	2021	Jun	Correia-Oliveira & Andrade-Souza	Soccer	England, Germany, Italy, Spain	Win ratio; Points; Goals; Team quality
18	2021	Jul	Fischer & Haucap	Soccer	Germany	Win ratio; Points; Shots; Corner kicks; Player market value; Table position; Rest pause from last match; Points earned in last three matches; Travel distance; Altitude; New coach; Derby; Matchday; Daytime; Stadium running track; Share standing places; Stadium capacity; Fouls; Yellow cards
19	2021	Jul	Higgs & Stavness	American Football, Baseball, Basketball, Hockey	NFL, MLB, NBA, NHL	Points
20	2021	Jul	Benz & Lopez	Soccer	Austria, Denmark, England, Germany, Greece, Italy, Norway, Portugal, Russia, Spain, Sweden, Switzerland, Turkey	Goals; Yellow cards
21	2021	Aug	Link & Anzer	Soccer	Germany	Win ratio; Goals; Expected Goals; Shots; Ball possession; Passes; Outplayed opponents; Pressure; Duels; Running activity; Contact times; Fouls; Yellow cards
22	2021	Aug	Leitner & Richlan	Soccer	Austria, Czech Republic, England, Germany, Italy, Russia, Spain, Turkey	Win ratio; Fouls; Yellow cards
23	2021	Aug	Guérette et al.	Hockey	NHL, Canadian Hockey League	Penalties
24	2021	Aug	Rovetta & Abate	Soccer	Italy	Points; Passes; Fouls; Cards; Penalty kicks
25	2021	Aug	Meier et al.	Soccer	England, Germany, Italy, Spain; Betting odds	Winning probability; Betting market pricing
26	2021	Aug	Losak & Sabel	Baseball	MLB; Betting odds	Win ratio; Batting order in the inning; Number of prior games played; Travel fatigue; Team ability; Betting market pricing
27	2021	Aug	Ramchandani & Millar	Soccer	England, Germany, Italy, Portugal, Spain	Win ratio; Points
28	2021	Sep	McCarrick et al.	Soccer	Austria, Denmark, England, Germany, Greece, Italy, Portugal, Russia, Spain, Switzerland, Turkey	Points; Goals; Shots; Shots on target; Corner kicks; Team dominance; Fouls; Yellow cards
29	2021	Oct	Sedeaud et al.	Soccer, Rugby	Belgium, England, France, Germany, Greece, Italy, Portugal, Scotland, Spain, Turkey, Celtic League	Win ratio
30	2021	Nov	Bilalić et al.	Soccer	Austria, England, Germany, Greece, Italy, Portugal, Spain, Turkey	Points; Goals; Shots; Shots on target; Corner kicks; Fouls; Cards
31	2021	Dec	Ungureanu at el.	Rugby	England, France, South Africa, New Zealand	Win ratio; Points, Substitution; Scored try; Penalty try; Missed penalty; Kick at goal; Cards
32	2021	Dec	Reade et al.	Soccer	France, Italy, European cup competitions	Win ratio; Goals; Attendance; Cards; Penalty kicks

33	2021	Dec	Arboix-Alió et al.	Rink Hockey	Italy, Portugal, Spain	Points, Goals; Set-pieces shots; Table position; Fouls; Blue and red cards
34	2022	Jan	Ghahfarokhi et al.	Soccer	England, France, Germany, Italy, Spain	Points; Goals scored; Goals conceded
35	2022	Jan	Gong	Basketball	NBA	Foul call; Player all-star status; Player nationality; Seconds left in the match; Nationally televised game; Point spread; Score differential; Referee age; Referee experience
36	2022	Jan	Vandoni et al.	Soccer	Italy	Points; Fouls, Cards; Penalty kicks
37	2022	Feb	Ribeiro et al.	Soccer	Brazil	Win ratio; Points; Goals scored; Goals conceded
38	2022	Feb	Alonso et al.	Basketball	Germany, Greece, Israel, Italy, Spain	Win ratio; Team ability (seasonal winning percentage)
39	2022	Mar	Fischer & Haucap	Soccer	Germany; Betting odds	Win ratio; Points; Shots; Corner kicks; Table position; Player market value; Betting market pricing; Fouls; Yellow cards
40	2022	Mar	Sors et al.	Soccer	UEFA Nations League	Win ratio; Points; Goals; Shots; Shots on goal, Ball possession; Corner kicks; Attendance; Fouls; Cards; Penalty kicks; Extra time
41	2022	Mar	Lee et al.	Soccer	England, Germany, Italy, Spain; Match estimated home advantage model	Expected score; Goal difference
42	2022	Apr	Macedo-Rego	Soccer	Brazil	Win ratio; Goals; Points; Scoring the first goal; Team strength; Crowd size
43	2022	Apr	Jiang et al.	Soccer	China	Win ratio; Shots; Shots not on target; Touches; Passes; Corner kicks; Aerial duels; Offside; Dribbles; Take on; Interception; Tackles; Crosses; Match location; Foul; Cards
44	2022	Apr	Ehrlich & Potter	Basketball	NBA	Points; Team strength; Team-specific fatigue; Travel distance; Win shares of missing players; Days rest since last game; Attendance; Free throw attempts; Personal fouls
45	2022	Apr	Morita & Araki	Soccer	Japan	Fouls; Yellow cards
46	2022	Apr	Bustamante-Sánchez et al.	Basketball	NBA	Points; Field goals; Rebounds; Assists; Transitions; Cuts; Pick-and-roll; Pick-and-pop; Fouls
47	2022	May	Szabó	Basketball, American Football, Hockey	NBA, NFL, NHL	Win ratio; Points; Attendance; Penalty kicks
48	2022	May	Fazackerley et al.	Rugby	NRL - Australia and New Zealand	Decoys; Post-contact meters; Support runs; Tackle breaks; Missed tackles; Total distance; High-speed running
49	2022	May	Cross & Uhrig	Soccer	England, Germany, Italy, Spain	Win ratio; Goals; Expected goals; Stadium distance; Daily weather
50	2022	May	Chiu & Chang	Baseball	MLB	Win ratio; Wins above replacement
51	2022	May	Destefanis et al.	Soccer	England, France, Germany, Italy, Spain	Points; Goals scored; Goals conceded; Shots; Ball possession; Dribbles; Through balls; Cross; Tackles; Attendance; Penalties attempted; Penalties converted
52	2022	Jun	Couto & Sayers	Soccer	Brazil	Win ratio; Points; Goals; Cards; Extra time

© 2024 ARD Asociación Española

53	2022	Jul	Chen et al.	Soccer	China	Total distance; Sprint distance/efforts; High-speed running distance/efforts; High-intensity running distance/efforts; Ball possession; Shots; Shots accuracy; Passes; Cross; Ground duel/won; Air duel/won; Tackles/won; Corner kicks; Table position; Fouls; Offside
54	2022	Aug	Steinfeldt et al.	Basketball	NBA	Points; Matchday; Batting odds; Attendance
55	2022	Aug	Silva et al.	Soccer	Brazil	Win ratio; Points; Goals; Corner kicks; Shots; Ball possession; Absent athletes; Fouls; Cards
56	2022	Aug	Krumer & Smith	Soccer (Women)	Sweden	Win ratio; Points; Goals; Betting odds; Cards
57	2022	Sep	Nomura	Soccer	Japan	Points; Goals; Goal shots; Corner kicks; Running distance; Sprints; Attendance; Cards
58	2022	Sep	Paulauskas et al.	Basketball	Euroleague Basketball	Win ratio; Points; Free throws attempted; Free throws made; Turnovers; Three-point shots attempted; Three-point shots made; Two-point shots made; Ball possession; Offensive rebounds; Blocks; Steals; Fouls; Technical fouls
59	2022	Sep	De Angelis & Reade	Basketball	Adriatic League (Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, Serbia, Slovenia), France, Germany, Greece, Israel, Italy, Lithuania, Russia, Spain, Turkey; Betting odds	Win ratio; Betting market pricing
60	2022	Oct	Piancastelli et al.	Soccer	England	Goals
61	2022	Oct	Ferraresi & Gucciardi	Soccer	England, France, Germany, Italy, Spain	Points; Teams' international experience; Quality of opponents (Quota paid by bookmakers); Attendance

Note. The publication date of items no. 3, 21, 27, 32, 33, 40, 44, 45, 49, 52, 56, 59, 60 and 61 represents an early, pre-print online publication date; Items no. 8, 9, 25, 26, 39, and 59 investigated the betting market efficiency in light of the transition to playing games behind closed doors; The list of domestic leagues analysed (in alphabetical order): Albania, Australia, Austria, Belgium, Bosnia and Herzegovina, Brazil, Canada, China, Costa Rica, Croatia, Czech Republic, Denmark, England, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Lithuania, Montenegro, New Zealand, North Macedonia, Norway, Poland, Portugal, Romania, Russia, Scotland, Serbia, Slovenia, South Africa, Spain, Sweden, Switzerland, Turkey, Ukraine, United States, Wales.

The literature is rich in studies indicating that referees tend to favour the home team – consciously or unconsciously – in their decision making, and that this favouritism is assumed to be caused by social pressure (e.g. Buraimo et al., 2010, 2012; Dohmen, 2008; Page & Page, 2010). Clear indications of biased calls made by the referee can be found with regard to fouls (e.g. Balmer et al., 2007; Nevill et al., 2002; Sapp et al., 2018), yellow cards (e.g. Balmer et al., 2007; Goumas, 2014; Unkelbach & Memmert, 2010), red cards (e.g. Dawson et al., 2007; Pettersson-Lidbom & Priks, 2010), penalties (e.g. Armatas & Pollard, 2014), and extra injury time at the end of a match (e.g. Garicano et al., 2005; Scoppa, 2008; Sutter & Kocher, 2004). Data from the German Bundesliga also shows that referee bias greatly increases when there is no running track that separates between the supporters and the pitch (Buraimo et al. 2010).

The underlying mechanism of the crowd's impact on the referees' judgment calls remains unclear. One possibility is that referees either use crowd noise (volume and intensity) as a decision heuristic (e.g. how severe a foul is), or as useful additional information for guiding their decision making. One common, normative type of conformity effects suggests that sports officials strive to satisfy the crowd in the stadium, thereby demonstrating agreement with the opinion of the more dominant crowd (Myers et al., 2014). It is also possible that referees might feel intimidated by the crowd in a way that influences their ability to conduct a fair match. For example, Anders and Rotthoff (2014) found that part of the home-field bias arises from the prospect of fan violence. However, typical crowd behaviours at sporting events, as well as the extent to which referees are willing to please the home crowd, are apparently subject to cultural differences and therefore may vary between countries (Gelade, 2015).

It also remains to be determined whether crowd noise affects referees differently, with some referees being more prone to crowd influence than others (Page & Page, 2010). Nevill et al. (2002), for example, found in their experiments that highly experienced referees were as biased towards the home team as less experienced ones – suggesting that expert referees may not be more capable of applying improved strategies for coping with stressors, such as crowd support, when making decisions. However, other studies have reached different conclusions. For example, an analysis of real-match data showed that the more experienced and skilled soccer referees were less susceptible to home team effects in terms of issuing yellow cards to the visiting team (Goumas, 2013). Moreover, referees who showed a tendency to over-involve consciousness in decision making made less decisions in favour of the home team compared to those who were categorized as high "*decision ruminators*" (Poolton et al., 2011). These individual differences must be taken into consideration when striving to decrease home bias and improve referee practices.

Laboratory experiments have manipulated crowd noise through the use of video-recorded tackles with and without crowd noise. Balmer et al. (2007) and Nevill et al. (1999, 2002), for example, found that refereeing in the presence of crowd noise resulted in a significant imbalance of decisions in favour of the home team, as well as fewer fouls against the home players, compared to the "*no noise*" condition. Unkelbach and Memmert (2010) improved on previously designed laboratory set-ups by using a larger sample of videos, with high and low volumes of crowd reactions to fouls at different stadiums. The study demonstrated the impact of crowd noise on referees' yellow card decisions, whereby more yellow cards were given to the visiting team when crowd noise was present, compared to the fewer penalties given to the home team.

While experimental designs enable the exclusion of certain confounding effects that could threaten the internal validity of the study, the referees who participated in these experiments were not making decisions in front of a live crowd who cared about their decisions, as in real live stadiums. To enhance external validity, Myers and Balmer (2012) conducted a unique controlled experiment using a live tournament setting, at venues of various sizes, with various crowd sizes and crowd densities, and qualified judges with varying experience. The study used a combat sport with varying levels of competition. In the 'no noise' condition, judges had noise-cancelling headphones. The results showed a significant difference in points in favour of the home fighter for the live "*crowd noise*" condition, across all settings.

One possible explanation for inconsistent decisions made by referees, in crowd noise compared to quiet conditions, could stem from the referees' increased stress during the game. Using a single measure of bias, Balmer et al. (2007) found that referees who exhibited greatest HA bias were more likely to have higher levels of cognitive anxiety and exercise greater mental effort when performing the task. This implies that to avoid negative consequences of anxiety, when making unpopular decisions against the home team (which are likely to produce vociferous crowd noise), referees tend to award fewer decisions against the home team.

 © 2024 ARD Asociación Española

Some studies suggested that supportive crowds may not necessarily result in superior home performances (e.g. Strauss, 2002) – and in some cases (e.g. when the stakes are extremely high) might even have a detrimental effect on performance (Wallace et al., 2005). As such, Balmer et al. (2007) attributed the imbalance that they found, in favour of home competitors, to the referees' biased decisions due to crowd noise – rather than to superior home performance.

HA: The perspective of key stakeholders

While the actual effects of the HA and referee bias have been widely investigated, especially in relation to the crowd, the beliefs and perceptions of fans, athletes, coaches, and officials have only attracted marginal research attention (Fothergill et al. 2014). The existing studies show that in general, fans, and even the media, believe that the crowd is the main cause of HA (Smith, 2005). For example, English soccer fans reported that they are able to affect the outcome of a match by motivating their team, distracting the opponents, and biasing the referees' decisions (Wolfson et al., 2005). Yet fans perceived officials to be more influenced by the teams' ranking than by the location of the game. Relatively stronger perceptions, about their ability to bias officials to favour the home team, were found among fans in the American Football League (Goldschmied & Hochuli, 2014). The officials themselves, on the other hand, perceived the fans' impact on their decisions to be negligible, but in their opinion other officials are slightly affected by the fans. However, both officials and fans believe that fans contribute to the HA through their ability to affect the athletes' performances (Goldschmied & Hochuli, 2014).

Similar perceptions were found in a survey of soccer players, fans, and referees in England, with the three groups attributing the HA mainly to crowd support and environmental familiarity (Anderson et al., 2012). As expected, referees in the study reported that they are robust to the crowd effect. Previously, athletes had reported travel-related factors as being one of the three most important variables that impact HA (Bray & Widmeyer, 2000). A more recent survey of a handball premier league, conducted with these target groups, including coaches, provided overall support for previous research, whereby the crowd is perceived as the most important factor that contributes to the HA phenomenon (Gershgorn et al., 2021). However, differences were found between groups. While fans over-ranked their contribution to the HA effect, officials under-ranked their contribution to this bias in comparison to the other groups. The players in the study ranked their own related factors (i.e. familiarity, travel, territory, and psychological attributes) as high in importance, yet coaches emphasized external factors, such as travel and officiating, that are beyond their control. The authors attributed these differences to self-serving bias, whereby each group strives to protect her ego, i.e., to achieve feelings of pride, or at the very least, to avoid feeling embarrassed.

Indeed, the question of how different groups perceive the HA and its causes is important and may affect the formation and rate of this phenomenon. Yet it is important to expand the existing literature on the topic of these stakeholders' view, about the causes of HA in general, and the crowd effect in particular, as the literature is lacking in this area.

DISCUSSION

The HA has been extensively studied, mainly in team sports, with officiating bias attracting research attention as one of its major causes. Our review shows that HA is elevated in sports that entail higher levels of physical contact (e.g. rugby, soccer, and basketball); when there are larger crowds; when competitions are held in smaller stadiums; and when the crowd is physically closer to the pitch. However, while crowd effects are present across many sports, it is difficult to determine whether the influence of the crowd on HA is primarily due to player performance (e.g. exhibiting greater dominance, confidence, or aggressive behaviours; Furley et al., 2018) or referee bias (e.g. favourable decisions toward the home team; Sutter & Kocher, 2004). Our review shows that the literature supports the referee bias to be the most important and dominant explanation in soccer. Yet, evidence from other sports suggests that either, or both, mechanisms are plausible. For most sports, the extent to which matches are influenced by either mechanism is difficult to assess.

As much as HA arises from referees favouring the home team, sport organizations are undoubtedly interested in reducing human error for reasons of fairness. Later in this review, we will discuss the ways sport organizations are taking to reduce referee bias. However, they might probably be less interested in reducing the HA that results from an elevated performance of players when competing at home, because games become more competitive and exciting. This makes the HA not necessarily an effect that should be minimized.

Considering player performance, several studies have demonstrated that male players experience higher testosterone levels when competing at home (e.g. McGuire et al., 1992; Neave & Wolfson, 2003), which can elicit a range of psychological and behavioural responses, such as higher motivation or aggressiveness (Carré et al., 2006). However, the impact of competing at home in front of a domestic audience, regardless of the type of sport, can vary among athletes. While it may boost confidence levels and outcome expectations for some athletes, leading to improved performance, it can also increase pressure to perform well for others, resulting in poor performance due to stress and over-cautiousness (Harb-Wu & Krumer, 2019; Wallace et al., 2005), known as the "*home disadvantage*" effect (Baumeister & Steinhilber, 1984). The athlete's experience might play a role as well (Sánchez & Lavín, 2020).

The possibility to study the effects of crowd noise in an ecological context emerged by the matches played behind closed doors due to the COVID-19 pandemic. The studies examined how the crowd size influenced the HA, performance, and disciplinary decisions in the match. The pandemic also prevented close contact between players and referees, which could have also affected fouls and punishments. Our review of the research on crowd attendance have shown mixed results, with the majority of studies showing a positive effect of crowd presence on HA (e.g. Arboix-Alió, et al., 2022; Bryson et al., 2021; Correia-Oliveira & Andrade-Souza, 2021; Hill & Van Yperen, 2021; McCarrick, et al., 2021; Scoppa, 2021; Sors et al., 2021), while others found no changes in HA over the seasons analysed (e.g. Almeida & Leite, 2021; Benz & Lopez, 2021; Matos et al., 2021; Wunderlich et al., 2021).

With the outbreak of the epidemic, it has also become possible to examine the socio-cultural and environmental robustness of HA, based on data collected from leagues within and across countries. Our review shows that the decrease in HA during ghost games varied between the different studies and seems to depend on different factors, including playing levels (e.g. first vs. second divisions) and country (e.g. German Bundesliga vs. English Premier League). For example, variation in the dynamics of HA was found in German soccer teams, with the first Bundesliga showing a more drastic reduction in HA than teams in the second and third league (Fischer & Haucap, 2021). It was suggested that playing without crowds had a much greater effect on teams that normally play in front of larger crowds at their stadiums. Likewise, Ribeiro et al. (2022) identified in Brazilian elite soccer (Series A and B) a decrease in HA only for Serie A in the absence of crowd, while Serie B analyses indicated no changes in HA over the three seasons analysed. Interestingly, the reduction in the advantage of playing at home for Serie A was found not only in the 2020 season, when there was no crowd support in the stadiums, but also in the 2019 season, when fans were present in the stadiums – compared to the 2018 season. This indicates the existence of other modulating factors of the HA effect.

 © 2024 ARD Asociación Española

Variations in HA levels between countries and populations within regions can be explained by social and cultural differences, as suggested by Pollard (2006) and Pollard et al. (2017). Yet environmental conditions may also play a significant role in HA. For example, van Damme and Baert (2019) found that soccer teams with a high-altitude home stadium (i.e. low oxygen levels) were more likely to win against teams from sea-level stadiums. Given the abundance of literature on HA, future research should focus on additional potential factors that contribute to the HA, as with van Damme and Baert (2019), rather than continuing to simply validate its existence. Part of the "*unresolved puzzle*" is the interaction of causes, which poses a challenge to investigate, isolate, and quantify how each likely cause operates with the other to establish the HA, as outlined by Pollard (2008).

Theories related to the impact of social pressure and conformity offer possible explanations for the decreased HA in ghost games. For example, Sors et al. (2021) argued that crowd noise/presence has a direct effect on referee bias, due to its related social pressure, as well as a direct and indirect effect on HA – as illustrated in Figure 2. While the *direct* effect stems from the crowd's support for the home team and/or the booing of the visiting team (Greer, 1983), the *indirect* effect is due to the occurrence of referee bias. The stadium capacity, the distance to the field, and the atmosphere created by a roaring crowd contribute to both phenomena. Thus, strategies for reducing referee bias – by coping more effectively with social pressure conveyed by the crowd – are of the utmost importance. It is worth noting, however, that although crowd is a major source of HA and referee bias (Endrich & Gesche, 2020), the evidence indicates that crowds do not have to exist in order for HA to occur – as additional factors can contribute to such bias during matches.

From a sport psychologist perspective, the COVID-19 pandemic provided a unique global opportunity for researching the emotional behaviour of players and referees (Webb, 2021). However, existing studies on this topic are scarce, with one example being the work of Leitner and Richlan (2021a). Using a video-based analysis system of nonverbal behaviour during soccer matches, the authors found that there were about 20% less emotional situations in matches without spectators, and that referees were significantly less actively involved in these emotional situations. In addition, limited attention has also been paid to exploring how the absence of fans affects the subjective experiences of players and officials, and their consequent behaviour.

Beyond the specific circumstances created by the pandemic, psychological factors are believed to play a major role in determining HA in team sports (Neave & Wolfson, 2004). One such factor is the mental attitude of players, coaches, and referees about the likelihood of winning the game when playing at home. According to Pollard (2008), such state of mind acts as a self-fulfilling phenomenon that impacts behaviour and actions, and consequently the outcome of the game and the role played by HA. Moreover, there is consistent evidence suggesting that athletes and coaches psychological states are superior when playing at home, in terms of their personal confidence and confidence in their team, as well as their emotions and mood states (Carron & Paradis, 2014). The findings support the proposal by Courneya and Carron (1992) that psychological states are influenced by game location (Terry et al., 1998). In contrast, athletes feel intimidated when competing away from home in front of unfavourable crowd. These findings lead to the conclusion that players should be better prepared to cope with the perceived disadvantage of playing away from home and the related emotions that accompanied it.

As outlined throughout this review, referee biased-decisions are thought to contribute to HA. For example, referees in Boyko et al.'s (2007) study exhibited significantly different HA in penalties and yellow cards, which the authors considered of being two potentially game-changing factors. Likewise, Nevill and Holder (1999) argued that it only takes 2 or 3 crucial decisions to go against the away team or in favour of the home team to give the side playing at home the "*edge*" during the game. However, it would be interesting to assess, for example, the exact impact of additional 1 or 2 yellow cards for the away team on the probability of victory for the home team. One such attempt was made by Anders and Rotthoff (2010). Using two regression models, the authors found in their data from the Bundesliga that yellow and red cards negatively impact the probability of winning games. As expected, when the *home* team receives a yellow card, it decreases their probability of winning by 13 to 15 percent (depending on the model used). One player receiving two yellow cards decreases the probability of the home team winning by 22 to 27 percent, and receiving a direct red card decreases the probability of victory by 44 to 48 percent. These results were significant at the one percent level.

More important to our discussion is the away team cards. It was found that when the *away* team receives a yellow card, it increases the probability that the home team wins by 5 to 6 percent, although these estimates are insignificantly different from zero. A yellow to red card for the away team increases the home team's chances of winning by 16 percent in one of the regression models ($p = 0.05$), and receiving a direct red card increases these chances by 20 to 25 percent ($p = 0.01$). A robustness test showed that although the model had a relatively low predictive power, the estimates gave an accurate measure of the effects of yellow and red cards in soccer matches. Clearly, it is a direction in which further research is needed.

Several other potential directions for future research emerged from our review. We found that most previous studies were focused on analysing the interaction between one specific variable and match location (e.g. type of competition, score-line, quality of opposition). Therefore, a topic that needs further exploration relates to the interacting effects of several situational variables with HA. This might be achieved thorough the development of new methods and models for the analysis of HA from a multivariate perspective.

Our review also shows that the analysis of individual and dual sports, as well as female competitors is sparse. Specific to women's sports, the HA effect has been demonstrated and studied mostly in basketball, volleyball, and soccer, with a consistently smaller effect for women than it is for men (Pollard & Gómez, 2014). These differences in the HA effect between women and men can be explained by physiological factors (e.g. hormonal effect; Bateup et al., 2002) or lesser crowd support in female competitions. However, the analysis of the exact causes and the way in which the different factors operate still remains a challenge for the future.

Not only is the research on women's sports limited, but so is the research on amateur and non- and semi-professional leagues, including collegiate and youth sports. At these lower levels of play, players' experience/expertise and playing conditions (e.g. training facilities or hours of practice) are generally poorer than those at the higher levels. The results from the different studies are inconsistent. Although the same factors of HA likely affect all different competitive levels (i.e. familiarity, travel effects, crowd support, referee bias, etc.), these factors may affect players and teams' performances in different ways and intensities. Hence, it is important to study the magnitude of HA at different competitive levels, and the possible causes of HA at different levels of play.

Finally, we found that little work has been done to examine individual differences in referees' respond to factors such as crowd noise (e.g. the referee emotional state, coping strategies, and social interaction abilities) when examining the HA, as outlined, for example, by Dosseville et al. (2016) and Boyko et al. (2007). If the subjective decisions of referees vary between individuals (after controlling for other factors, such as team abilities), we would expect the home bias to systematically differ between referees. Taking such individual differences into consideration would allow better predicting and coping with the home bias.

 © 2024 ARD Asociación Española

While this review is informative and involves an extensive search of the literature, there are limitations that have to be considered. First of all, relevant evidence may have been omitted from this review if they were not identified through the applied search methods. Moreover, as with almost any review, there might be an element of selection bias. However, these concerns may be alleviated somewhat because the sample of studies included in this narrative review is quite large and may adequately represent the overall picture. A possible bias of single studies may also occur, due to the measures used by researchers for capturing the HA and referee bias, while overlooking other possible independent variables that should be controlled (e.g. team strength, travel distance, and venue size). In some cases, this could distort valid comparisons between teams, leagues, or sports. Finally, attention should also be paid to differences that may be seen in the interpreting of results in the different studies, as not all researchers and studies apply the same scaling methods (see the recommendations by Jones, 2018).

Reducing the HA effect and referee bias

Over time, positive changes have been seen in HA in a range of professional leagues (e.g. English and Scottish soccer; Nevill et al., 2013), corresponding with significant improvements in referee training. However, the smallest decrease has been observed in higher divisions with larger crowds, such as ice hockey, basketball, and soccer (Webb et al., 2018). An interesting attempt to compensate for the home team advantage has been made by several leagues, such as the UK Motorcycle Speedway League, by awarding an extra point for an away win (three points instead of two). This change to the scoring system led to an approximate 30% reduction in the HA effect for this particular sport. Unfortunately, no other research evidence was found in the articles reviewed in this paper.

In the interest of fairness, sports organizations have taken several steps to reduce judgment errors made by the officials. For example, the Union of European Football Associations (UEFA) experimented with two additional assistant referees during Champions League and Europa League matches in the 2008/9-2011/12 seasons – resulting in decreased home or "*big*" team favouritism, and an increase in yellow cards issued for both home and away teams (Albanese et al., 2020). In addition, referees in a number of sports are now allowed to correct erroneous decisions through a third-party assistant, often someone who has access to technological monitoring.

Today, monitoring devices are increasingly used in sports for reducing human error, such as the Video Assistant Referee (VAR) in soccer, video replay in basketball and field hockey, computer guided cameras in tennis and cricket (the Hawk-Eye), and the Television Match Official (TMO) in rugby. While VAR has changed the dynamics of soccer games in several leagues (e.g. Lago-Peñas et al., 2019), yet technology have not necessarily improved balance in decision making when considering the HA bias (Dawson et al., 2020; Han et al., 2020). For certain sporting events, such as the semi-finals and finals in the English men's soccer league, improved control of HA and referee bias is obtained by holding games at neutral sites (e.g. the Wembley Stadium). Yet evidence is lacking regarding reduced favouritism and bias at different levels of competition (e.g. playoffs).

The training of professional referees has also greatly improved over time, extending beyond traditional physical training programs (Weston, 2015). The introduction of new technologies, such as the Prozone and Opta systems for performance analysis, is a huge step forward for referee training. Nowadays, structured training sessions in decision making are also more common (Webb et al., 2018), with referees analysing each of their decisions through video recordings of their actual matches. The shared mental model video-based training approach, for example, was found to have a positive impact on decisions made by Rugby Union referees (Mascarenhas et al., 2005).

While referees need physical fitness training for coping with fatigue and keeping up with the game (Castagna et al., 2007), they also require adequate psychological preparation (Lane et al., 2006). In some sports clubs, referees work closely with designated referee coaches and mentors, to provide them with additional support and training. Studies show that training can help referees become increasingly aware of external crowd pressure, while learning how to apply effective strategies for filtering out such pressure. For example, referees must learn to cope with stress that is associated with their making unpopular decisions, while practicing how to demonstrate greater confidence in their decision making (Di Corrado et al., 2011).

Higher levels of professionalism following improved referee training are clearly noticeable. For example, evidence of more balanced decisions made by referees was reported by Rickman and Witt (2008), with no indication of favouritism effects in close matches in relation to extra time due to injury. Similarly, no evidence of the HA effect due to crowd size and referee bias was found over several seasons of the English soccer Premiership (Johnston, 2008). As such, governing bodies should further improve the training of their officials as a means for reducing HA and referee bias. In addition, due to individual differences (Poolton et al., 2011), there is a need to identify those referees who may be prone to negative effects of external stimuli, such as crowd noise, and pro-actively provide them with training alternatives that can improve their performance (e.g. training in environments with live audience). Greater professionalization also includes the mental preparation of athletes as part of their training process to increase their mental resilience, thereby contributing to a further decline of HA. From a scientific perspective, more research is needed regarding the mechanisms through which crowd support contributes to physiological reactivity, attention, stress responses, and decision making by athletes and officials.

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

REFERENCES

Agnew, G. A., & Carron, A. V. (1994). Crowd effects and the home advantage. International Journal of Sport Psychology, 25(1), 53-62.

Albanese, A., Baert, S., & Verstraeten, O. (2020). Twelve eyes see more than eight: Referee bias and the introduction of additional assistant referees in soccer. PLoS ONE, 15(2): e0227758. https://doi.org/10.1371/journal.pone.0227758

Allen, M. S., & Jones, M. V. (2014). The "home advantage" in athletic competitions. Current Directions in Psychological Science, 23(1), 48-53. https://doi.org/10.1177/0963721413513267

Almeida, C. H., & Leite, W. S. (2021). Professional football in times of COVID-19: Did the home advantage effect disappear in European domestic leagues? Biology of Sport, 38(4), 693-701. https://doi.org/10.5114/biolsport.2021.104920

Alonso, E., Lorenzo, A., Ribas, C., & Gómez, M. A. (2022). Impact of COVID-19 pandemic on home advantage in different European professional basketball leagues. Perceptual and Motor Skills, 129(2), 328-342. https://doi.org/10.1177/00315125211072483

Anders, A., & Rotthoff, K. W. (2011). Yellow cards: Do they matter? Journal of Quantitative Analysis in Sports, 7(1), Article 9. https://doi.org/10.2202/1559-0410.1286

 © 2024 ARD Asociación Española

Anders, A., & Rotthoff, K. W. (2014). Is home-field advantage driven by the fans? Evidence from across the ocean. Applied Economics Letters, 21(16), 1165-1168. https://doi.org/10.1080/13504851.2014.914139

Anderson, M., Wolfson, S., Neave, N., & Moss, M. (2012). Perspectives on the home advantage: A comparison of football players, fans and referees. Psychology of Sport and Exercise, 13(3), 311-316. https://doi.org/10.1016/j.psychsport.2011.11.012

Arboix-Alió, J., Trabal, G., Buscà, B., Peña, J., Arboix, A., & Hileno, R. (2022). The behaviour of home advantage during the COVID-19 pandemic in European rink hockey leagues. International Journal of Environmental Research and Public Health, 19(1), Article 228. https://doi.org/10.3390/ijerph19010228

Armatas, V., & Pollard, R. (2014). Home advantage in Greek football. European Journal of Sport Science, 14(2), 116-122. https://doi.org/10.1080/17461391.2012.736537

Avugos, S., MacMahon, C., Bar-Eli, M., & Raab, M. (2021). Inter-individual differences in sport refereeing: A review of theory and practice. Psychology of Sport and Exercise, 55(1), Article 101926. https://doi.org/10.1016/j.psychsport.2021.101926

Balmer, N. J., Nevill, A. M., & Lane, A. M. (2005). Do judges enhance home advantage in European championship boxing? Journal of Sports Sciences, 23(4), 409-416. https://doi.org/10.1080/02640410400021583

Balmer, N. J., Nevill, A. M., Lane, A. M., Ward, P., Williams, A. M., & Fairclough, S. H. (2007). Influence of crowd noise on soccer refereeing consistency in soccer. Journal of Sport Behavior, 30(2), 130-145.

Balmer, N. J., Nevill, A. M., & Williams, A. M. (2001). Home advantage in the Winter Olympics (1908-1998). Journal of Sports Sciences, 19(2), 129-139. https://doi.org/10.1080/026404101300036334

Balmer, N. J., Nevill, A. M., & Williams, A. M. (2003). Modelling home advantage in the Summer Olympic Games. Journal of Sports Sciences, 21(6), 469-478. https://doi.org/10.1080/0264041031000101890

Bateup, H. S., Booth, A., Shirtcliff, E. A., & Granger, D. A. (2002). Testosterone, cortisol, and women's competition. Evolution and Human Behavior, 23(3), 181-192. https://doi.org/10.1016/S1090-5138(01)00100-3

Baumeister, R. F., & Steinhilber, A. (1984). Paradoxical effects of supportive audiences on performance under pressure: The home field disadvantage in sports championships. Journal of Personality and Social Psychology, 47(1), 85-93. https://doi.org/10.1037/0022-3514.47.1.85

Benz, L. S., & Lopez, M. J. (2021). Estimating the change in soccer's home advantage during the Covid-19 pandemic using bivariate Poisson regression. AStA-Advances in Statistical Analysis, 66(2), Article 6. https://doi.org/10.1007/s10182-021-00413-9

Bilalić, M., Gula, B., & Vaci, N. (2021). Home advantage mediated (HAM) by referee bias and team performance during covid. Scientific Reports, 11(1), Article 21558. https://doi.org/10.1038/s41598-021-00784-8

Boyko, R. H., Boyko, A. R., & Boyko, M. G. (2007). Referee bias contributes to the home advantage in English Premiership football. Journal of Sports Sciences, 25(11), 1185-1194. https://doi.org/10.1080/02640410601038576

Bray, S. R., & Widmeyer, W. N. (2000). Athletes' perceptions of the home advantage: An investigation of perceived causal factors. Journal of Sport Behavior, 23(1), 1-10.

Bryson, A., Dolton, P., Reade, J. J., Schreyer, D., & Singleton, C. (2021). Causal effects of an absent crowd on performances and refereeing decisions during Covid-19. Economics Letters, 198, Article 109664. https://doi.org/10.1016/j.econlet.2020.109664

Buraimo, B., Forrest, D., & Simmons, R. (2010). The 12th man? Refereeing bias in English and German soccer. Journal of the Royal Statistical Society, Series A, 173(2), 431-449. https://doi.org/10.1111/j.1467-985X.2009.00604.x

Buraimo, B., Simmons, R., & Maciaszczyk, M. (2012). Favoritism and referee bias in European soccer: Evidence from the Spanish league and the UEFA Champions league. Contemporary Economic Policy, 30(3), 329-343. https://doi.org/10.1111/j.1465-7287.2011.00295.x

Bustamante-Sánchez, Á., Gómez, M. A., & Jiménez-Saiz, S. L. (2022). Game location effect in the NBA: A comparative analysis of playing at home, away and in a neutral court during the COVID-19 season. International Journal of Performance Analysis in Sport, 22(3), 370-381. https://doi.org/10.1080/24748668.2022.2062178

Carré, J., Muir, C., Belanger, J., & Putnam, S. K. (2006). Pre-competition hormonal and psychological levels of elite hockey players: Relationship to the 'home advantage'. Physiology and Behavior, 89(3), 392-398. https://doi.org/10.1016/j.physbeh.2006.07.011

Carron, A. V., Loughhead, T. M., & Bray, S. R. (2005). The home advantage in sport competitions: The Courneya and Carron's (1992) conceptual framework a decade later. Journal of Sports Sciences, 23(4), 395-407. https://doi.org/10.1080/02640410400021542

Carron, A. V., & Paradis, K. F. (2014). Home advantage. In R. C. Eklund, & G. Tenenbaum (Eds.), Encyclopedia of sport and exercise psychology, part 1 (pp. 350-354). Sage.

Castagna, C., Abt, G., & D'Ottavio, S. (2007). Physiological aspects of soccer refereeing performance and training. Sport Medicine, 37(7), 625-646. https://doi.org/10.2165/00007256-200737070-00006

Chen, J., Zhai, S., Xi, Z., Li, P., & Zhang, S. (2022). Impact of absent crowds on technical and physical performances in the Chinese Soccer Super League. Frontiers in Psychology, 13, Article 959213. https://doi.org/10.3389/fpsyg.2022.959213

Chiu, Y. C., & Chang, C. K. (2022). Major League Baseball during the COVID-19 pandemic: Does a lack of spectators affect home advantage? Humanities and Social Sciences Communications, 9(1), Article 178. https://doi.org/10.1057/s41599-022-01193-6

Chun, S., & Park, S. S. (2021). Home advantage in skeleton: Familiarity versus crowd support. Journal of Sports Economics, 22(1), 3-26. https://doi.org/10.1177/1527002520936737

Collins, J. A., & Fauser, B. C. J. M. (2005). Balancing the strengths of systematic and narrative reviews. Human Reproduction Update, 11(2), 103-104. https://doi.org/10.1093/humupd/dmh058

Correia-Oliveira, C. R., & Andrade-Souza, V. A. (2021). Home advantage in soccer after the break due to COVID-19 pandemic: Does crowd support matter? International Journal of Sport and Exercise Psychology, 20(4), 1245-1256. https://doi.org/10.1080/1612197X.2021.1934716

Courneya, K. S., & Carron, A. V. (1990). Batting first versus last: Implications for the home advantage. Journal of Sport and Exercise Psychology, 12(3), 312-316. https://doi.org/10.1123/jsep.12.3.312

Courneya, K. S., & Carron, A. V. (1991). Effects of travel and length of home stand/road trip on the home advantage. Journal of Sport and Exercise Psychology, 13(1), 42-49. https://doi.org/10.1123/jsep.13.1.42

Courneya, K. S., & Carron, A. V. (1992). The home advantage in sport competitions: A literature review. Journal of Sport and Exercise Psychology, 14(1), 13-27. https://doi.org/10.1123/jsep.14.1.13

Couto, B. P., & Sayers, M. G. L. (2023). Crowd social pressure in the Brazilian soccer league: Testing home advantage and referees' bias during the COVID-19 pandemic. International Journal of Sport and Exercise Psychology, 21(4), 673-688. https://doi.org/10.1080/1612197X.2022.2084763

Cross, J., & Uhrig, R. (2023). Do fans impact sports outcomes? A COVID-19 natural experiment. Journal of Sports Economics, 24(1), 3-27. https://doi.org/10.1177/15270025221100204

Dawson, P., Dobson, S., Goddard, J., & Wilson, J. (2007). Are football referees really biased and inconsistent? Evidence on the incidence of disciplinary sanction in the English Premier League. Journal of the Royal Statistical Society: Series A (Statistics in Society), 170(1), 231-250. https://doi.org/10.1111/j.1467-985X.2006.00451.x

 © 2024 ARD Asociación Española

Dawson, P., Massey, P., & Downward, P. (2020). Television match officials, referees, and home advantage: Evidence from the European Rugby Cup. Sport Management Review, 23(3), 443-454. https://doi.org/10.1016/j.smr.2019.04.002
De Angelis, L., & Reade, J. J. (2023). Home advantage and mispricing in indoor sports' ghost games: The case of European basketball. Annals of Operations Research, 325(1), 391-418. https://doi.org/10.1007/s10479-022-04950-7
Destefanis, S., Addesa, F., & Rossi, G. (2022). The impact of COVID-19 on home advantage: A conditional order-m analysis of football clubs' efficiency in the top-5 European leagues. Applied Economics, 54(58), 6639-6655. https://doi.org/10.1080/00036846.2022.2074361
Di Corrado, D., Pellarin, E., & Agostini, T. A. (2011). The phenomenon of social influence on the football pitch: Social pressure from the crowd on referees' decisions. Review of Psychology, 18(1), 33-36.
Dohmen, T. J. (2008). The influence of social forces: Evidence from the behavior of football referees. Economic Inquiry, 46(3), 411-424. https://doi.org/10.1111/j.1465-7295.2007.00112.x
Dohmen, T., & Sauermann, J. (2016). Referee bias. Journal of Economic Surveys, 30(4), 679-695. https://doi.org/10.1111/joes.12106
Dosseville, F., Edoh, K. P., & Molinaro, C. (2016). Sports officials in home advantage phenomenon: A new framework. International Journal of Sport and Exercise Psychology, 14(3), 250-254. https://doi.org/10.1080/1612197X.2015.1023422
Ehrlich, J., & Potter, J. (2023). Estimating the effect of attendance on home advantage in the National Basketball Association. Applied Economics Letters, 30(11), 1471-1482. https://doi.org/10.1080/13504851.2022.2061898
Endrich, M., & Gesche, T. (2020). Home-bias in referee decisions: Evidence from "ghost matches" during the Covid19-pandemic. Economics Letters, 197, Article 109621. https://doi.org/10.1016/j.econlet.2020.109621
Erikstad, M. K., & Johansen, B. T. (2020). Referee bias in professional football: Favoritism toward successful teams in potential penalty situations. Frontiers in Sports and Active Living, 2, Article 19. https://doi.org/10.3389/fspor.2020.00019
Fazackerley, L. A., Gorman, A. D., Minett, G. M., Caia, J., & Kelly, V. G. (2022). The influence of absent crowds on National Rugby League match player statistics and running metrics. Psychology of Sport and Exercise, 60, Article 102163. https://doi.org/10.1016/j.psychsport.2022.102163
Ferraresi, M., & Gucciardi, G. (2021). Who chokes on a penalty kick? Social environment and individual performance during Covid-19 times. Economics Letters, 203, Article 109868. https://doi.org/10.1016/j.econlet.2021.109868
Ferraresi, M., & Gucciardi, G. (2023). Team performance and the perception of being observed: Experimental evidence from top-level professional football. German Economic Review, 24(1), 1-31. https://doi.org/10.1515/ger-2021-0104
Fischer, K., & Haucap, J. (2021). Does crowd support drive the home advantage in professional football? Evidence from German ghost games during the COVID-19 pandemic. Journal of Sports Economics, 22(8), 982-1008. https://doi.org/10.1177/15270025211026552
Fischer, K., & Haucap, J. (2022). Home advantage in professional soccer and betting market efficiency: The role of spectator crowds. Kyklos, 75(2), 294-316. https://doi.org/10.1111/kykl.12291
Fontenla, M., & Izón, G. M. (2018). The effects of referees on the final score in football. Estudios Económicos, 35(70), 79-97. https://doi.org/10.52292/j.estudecon.2018.1098
Fothergill, M., Wolfson, S., & Little, L. (2014). A qualitative analysis of perceptions of venue: do professional soccer players and managers concur with the conceptual home advantage framework? International Journal of Sport and Exercise Psychology, 12(4), 316-332. https://doi.org/10.1080/1612197X.2014.932826

Franchini, E., & Takito, M. Y. (2016). Home advantage in combat sports during the Olympic games. Sport Sciences for Health, 12(3), 287-290. https://doi.org/10.1007/s11332-016-0286-9
Furley, P., Schweizer, G., & Memmert, D. (2018). Thin slices of athletes' nonverbal behavior give away game location: Testing the territoriality hypothesis of the home game advantage. Evolutionary Psychology, 16(2), 1-12. https://doi.org/10.1177/1474704918776456
Fuxjager, M. J., Mast, G., Becker, E. A., & Marler, C. A. (2009). The 'home advantage' is necessary for a full winner effect and changes in post-encounter testosterone. Hormones and Behavior, 56(2), 214-219. https://doi.org/10.1016/j.yhbeh.2009.04.009
Garicano, L, Palacios-Huerta, I., & Prendergast, C. (2005). Favoritism under social pressure. Review of Economics and Statistics, 87(2), 208-216. https://doi.org/10.1162/0034653053970267
Gelade, G. A. (2015). National culture and home advantage in football. Cross-Cultural Research, 49(3), 281-296. https://doi.org/10.1177/1069397114556055
Gershgorn, L., Levental, O., & Basevitch, I. (2021). Home advantage perceptions in elite handball: A comparison among fans, athletes, coaches, and officials. Frontiers in Psychology, 12, Article 782129. https://doi.org/10.3389/fpsyg.2021.782129
Ghahfarokhi, E. A., Soroush, S., & Hasanbeigi, H. (2022). Investigating the home advantage in the world's prestigious football leagues before and after the outbreak of COVID-19. Revista Brasileira de Futsal e Futebol, 14(57), 119-129.
Goldschmied, N., & Hochuli, R. (2014). Do fans and officials think alike when assessing the home-field advantage? Support for actor-observer asymmetry in the National Football League. Basic and Applied Social Psychology, 36(2), 155-163. https://doi.org/10.1080/01973533.2014.882258
Gómez, M. A., Gasperi, L., & Lupo, C. (2016). Performance analysis of game dynamics during the 4th game quarter of NBA close games. International Journal of Performance Analysis in Sport, 15(1), 249-263. https://doi.org/10.1080/24748668.2016.11868884
Gómez-Ruano, M. A., Pollard, R., & Lago-Peñas, C. (Eds.). (2021). Home advantage in sport: Causes and the effect on performance. Routledge. https://doi.org/10.4324/9781003081456
Gómez, M. A., Pollard, R., & Luis-Pascual, J. C. (2011). Comparison of the home advantage in nine different professional team sports in Spain. Perceptual and Motor Skills, 113(4), 150-156. https://doi.org/10.2466/05.PMS.113.4.150-156
Gong, H. (2022). The effect of the crowd on home bias: Evidence from NBA games during the COVID-19 pandemic. Journal of Sports Economics, 23(7), 950-975. https://doi.org/10.1177/15270025211073337
Goumas, C. (2013). Referee expertise and home-team bias in European football. International Journal of Sport Psychology, 44(5), 429-440.
Goumas, C. (2014). Home advantage and referee bias in European football. European Journal of Sport Science, 14(sup1), S243-S249. https://doi.org/10.1080/17461391.2012.686062
Greenhalgh, T. (2012). Outside the box: Why are Cochrane reviews so boring? British Journal of General Practice, 62(600), 371. https://doi.org/10.3399/bjgp12X652418
Greenhalgh, T., Thorne, S., & Malterud, K. (2018). Time to challenge the spurious hierarchy of systematic over narrative reviews? European Journal of Clinical Investigation, 48(6), Article e12931. https://doi.org/10.1111/eci.12931
Greer, D. L. (1983). Spectator booing and the home advantage: A study of social influence in the basketball arena. Social Psychology Quarterly, 46(3), 252-261. https://doi.org/10.2307/3033796
Guérette, J., Blais, C., & Fiset, D. (2021). The absence of fans removes the home advantage associated with penalties called by National Hockey League referees. PLoS ONE, 16(8): e0256568. https://doi.org/10.1371/journal.pone.0256568

 © 2024 ARD Asociación Española

Han, B., Chen, Q., Lago-Peñas, C., Wang, C., & Liu, T. (2020). The influence of the video assistant referee on the Chinese Super League. International Journal of Sports Science and Coaching, 15(5-6), 662-668. https://doi.org/10.1177/1747954120938984

Harb-Wu, K., & Krumer, A. (2019). Choking under pressure in front of a supportive audience: Evidence from professional biathlon. Journal of Economic Behavior and Organization, 166(2), 246-262. https://doi.org/10.1016/j.jebo.2019.09.001

Hegarty, T. (2021). Information and price efficiency in the absence of home crowd advantage. Applied Economics Letters, 28(21), 1902-1907. https://doi.org/10.1080/13504851.2021.1883525

Helsen, W., MacMahon, C., & Spitz, J. (2019). Decision making in match officials and judges. In M. Williams, & R. Jackson (Eds.), Anticipation and decision-making in sport (pp. 250-266). Routledge. https://doi.org/10.4324/9781315146270-14

Higgs, N., & Stavness, I. (2021). Bayesian analysis of home advantage in North American professional sports before and during COVID-19. Scientific Reports, 11(1), Article 14521. https://doi.org/10.1038/s41598-021-93533-w

Hill, Y., & Van Yperen, N. W. (2021). Losing the home field advantage when playing behind closed doors during COVID-19: Change or chance? Frontiers in Psychology, 12, Article 658452. https://doi.org/10.3389/fpsyg.2021.658452

Hüttermann, S., Helsen, W. F., Put, K., & Memmert, D. (2018). Does visual attention impact on decision making in complex dynamic events? Journal of Sport and Exercise Psychology, 40(3), 163-166. https://doi.org/10.1123/jsep.2017-0169

Jamieson, J. P. (2010). The home field advantage in athletics: A meta-analysis. Journal of Applied Social Psychology, 40(7), 1819-1848. https://doi.org/10.1111/j.1559-1816.2010.00641.x

Jehue, R., Street, D., & Huizenga, R. (1993). Effect of time zone and game time changes on team performance: National Football League. Medicine and Science in Sports and Exercise, 25(1), 127-131. https://doi.org/10.1249/00005768-199301000-00017

Jiang, J., Ge, H., & Cui, Y. (2022). Effect of tournament format change on team performance of Chinese Football Super League during COVID-19 pandemic. RICYDE-Revista International de Ciencias del Deporte, 18(68), 72-85. https://doi.org/10.5232/ricyde2022.06801

Johnston, R. (2008). On referee bias, crowd size, and home advantage in the English soccer Premiership. Journal of Sports Sciences, 26(6), 563-568. https://doi.org/10.1080/02640410701736780

Jones, M. B. (2013). The home advantage in individual sports: An augmented review. Psychology of Sport and Exercise, 14(3), 397-404. https://doi.org/10.1016/j.psychsport.2013.01.002

Jones, M. B. (2018). Differences in home advantage between sports. Psychology of Sport and Exercise, 34(3), 61-69. https://doi.org/10.1016/j.psychsport.2017.07.012

Koning, R. H. (2005). Home advantage in speed skating: Evidence from individual data. Journal of Sports Sciences, 23(4), 417-427. https://doi.org/10.1080/02640410400021625

Koning, R. H. (2011). Home advantage in professional tennis. Journal of Sports Sciences, 29(1), 19-27. https://doi.org/10.1080/02640414.2010.516762

Krumer, A. (2017). On winning probabilities, weight categories, and home advantage in professional judo. Journal of Sports Economics, 18(1), 77-96. https://doi.org/10.1177/1527002514560576

Krumer, A., & Smith, V. A. O. (2023). The effect of COVID-19 on home advantage in women's soccer: Evidence from Swedish Damallsvenskan. American Behavioral Scientist, 67(10), 1168-1178. https://doi.org/10.1177/00027642221118259

Laborde, S., Dosseville, F., & Raab, M. (2013). Emotions and decision making in sports: Introduction, comprehensive approach, and vision for the future. International Journal of Sport and Exercise Psychology, 11(2), 143-150. https://doi.org/10.1080/1612197X.2013.773686

Lago-Peñas, C., & Gómez-López, M. (2016). The Influence of referee bias on extra time in elite soccer matches. Perceptual and Motor Skills, 122(2), 666-677. https://doi.org/10.1177/0031512516633342

Lago-Peñas, C., Gómez, M. A., & Pollard, R. (2017). Home advantage in elite soccer matches. A transient effect? International Journal of Performance Analysis in Sport, 17(1-2), 86-95. https://doi.org/10.1080/24748668.2017.1304024

Lago-Peñas, C., & Martín, R. (2007). Determinants of possession of the ball in soccer. Journal of Sports Sciences, 25(9), 969-974. https://doi.org/10.1080/02640410600944626

Lago-Peñas, C., Rey, E., & Kalén, A. (2019). How does Video Assistant Referee (VAR) modify the game in elite soccer? International Journal of Performance Analysis in Sport, 19(4), 646-653. https://doi.org/10.1080/24748668.2019.1646521

Lane, A. M., Nevill, A. M., Ahmad, N. S., & Balmer, N. (2006). Soccer referee decision making: 'Shall I blow the whistle?' Journal of Sport Science and Medicine, 5(2), 243-253.

Lee, J., Kim, J., Kim, H., & Lee, J. S. (2022). A Bayesian approach to predict football matches with changed home advantage in spectator-free matches after the COVID-19 break. Entropy, 24(3), Article 366. https://doi.org/10.3390/e24030366

Leitner, M. C., Daumann, F., Follert, F., & Richlan, F. (2022). The cauldron has cooled down: A systematic literature review on home advantage in football during the COVID-19 pandemic from a socio-economic and psychological perspective. Management Review Quarterly, 73(2), 605-633. https://doi.org/10.1007/s11301-021-00254-5

Leitner, M. C., & Richlan, F. (2021a). Analysis system for emotional behavior in football (ASEB-F): Matches of FC Red Bull Salzburg without supporters during the COVID-19 pandemic. Humanities and Social Sciences Communications, 8(1), Article 14. https://doi.org/10.1057/s41599-020-00699-1

Leitner, M. C., & Richlan, F. (2021b). No fans - no pressure: Referees in professional football during the COVID-19 pandemic. Frontiers in Sports and Active Living, 3, Article 720488. https://doi.org/10.3389/fspor.2021.720488

Link, D., & Anzer, G. (2022). How the COVID-19 pandemic has changed the game of soccer. International Journal of Sports Medicine, 43(1), 83-93. https://doi.org/10.1055/a-1518-7778

Losak, J. M., & Sabel, J. (2021). Baseball home field advantage without fans in the stands. International Journal of Sport Finance, 16(3), 148-162. https://doi.org/10.32731/IJSF/163.082021.04

Luehring, F. W. (1923). Comparison between Eastern and Western basketball. The Athletic Journal, 6(2), 5-7.

Macedo-Rego, R. C. (2022). The effect of crowd support: Home advantage in football is reduced during the Coronavirus disease (COVID-19) pandemic. Behaviour, 159(10), 941-959. https://doi.org/10.1163/1568539X-bja10159

Mascarenhas, D. R. D., Collins, D., & Mortimer, P. W. (2005). A naturalistic approach to training accurate and coherent decision making in Rugby Union referees. The Sport Psychologist, 19(2), 131-147. https://doi.org/10.1123/tsp.19.2.131

Matos, R., Monteiro, D., Antunes, R., Mendes, D., Botas, J., Clemente, J., & Amaro, N. (2021). Home-advantage during COVID-19: An analysis in Portuguese Football League. International Journal of Environmental Research and Public Health, 18(7), Article 3761. https://doi.org/10.3390/ijerph18073761

McCarrick, D., Bilalic, M., Neave, N., & Wolfson, S. (2021). Home advantage during the COVID-19 pandemic: Analyses of European football leagues. Psychology of Sport and Exercise, 56, Article 102013. https://doi.org/10.1016/j.psychsport.2021.102013

McCarrick, D., Brewer, G., Lyons, M., Pollet, T. V., & Neave, N. (2020). Referee height influences decision making in British football leagues. BMC Psychology, 8(1), Article 4. https://doi.org/10.1186/s40359-020-0370-4

 © 2024 ARD Asociación Española

McGuire, E. J., Courneya, K. S., Widmeyer, W. N., & Carron, A. V. (1992). Aggression as a potential mediator of the home advantage in professional ice hockey. Journal of Sport and Exercise Psychology, 14(2), 148-158. https://doi.org/10.1123/jsep.14.2.148

McHill, A., & Chinoy, E. D. (2020). Utilizing the National Basketball Association's COVID-19 restart "bubble" to uncover the impact of travel and circadian disruption on athletic performance. Scientific Reports, 10(1), Article 21827. https://doi.org/10.1038/s41598-020-78901-2

Meier, P. F., Flepp, R., & Franck, E. (2021). Are sports betting markets semi-strong efficient? Evidence from the COVID-19 pandemic. International Journal of Sport Finance, 16(3), 111-126. https://doi.org/10.32731/IJSF/163.082021.01

Morita, H., & Araki, S. (2023). Social pressure in football matches: An event study of 'Remote Matches' in Japan. Applied Economics Letters, 30(11), 1522-1525. https://doi.org/10.1080/13504851.2022.2066617

Myers, T., & Balmer, N. (2012). The impact of crowd noise on officiating in Muay Thai: Achieving external validity in an experimental setting. Frontiers in Psychology, 3, Article 346. https://doi.org/10.3389/fpsyg.2012.00346

Myers, T. D., Gilson, T., & Allen, M. S. (2014). Achieving external validity in home advantage research: Generalizing crowd noise effects. Frontiers in Psychology, 5, Article 532. https://doi.org/10.3389/fpsyg.2014.00532

Neave, N., & Wolfson, S. (2003). Testosterone, territoriality, and the 'home advantage'. Physiology and Behavior, 78(2), 269-275. https://doi.org/10.1016/S0031-9384(02)00969-1

Neave N., & Wolfson S. (2004). The home advantage: Psychological and physiological factors in soccer. In D. Lavalle, J. Thatcher, & M. V. Jones (Eds.), Coping and Emotion in Sport (pp. 127-144). Nova Science.

Nevill, A., Balmer, N., & Williams, M. (1999). Crowd influence on decisions in association football. The Lancet, 353(9162), 1416. https://doi.org/10.1016/S0140-6736(99)01299-4

Nevill, A., Balmer, N. J., & Williams, A. M. (2002). The influence of crowd noise and experience upon refereeing decisions in football. Psychology of Sport and Exercise, 3(4), 261-272. https://doi.org/10.1016/S1469-0292(01)00033-4

Nevill, A. M., & Holder, R. L. (1999). Home advantage in sport: An overview of studies on the advantage of playing at home. Sports Medicine, 28(4), 221-236. https://doi.org/10.2165/00007256-199928040-00001

Nevill, A, Webb, T., & Watts, A. (2013). Improved training of football referees and the decline in home advantage post-WW2. Psychology of Sport and Exercise, 14(2), 220-227. https://doi.org/10.1016/j.psychsport.2012.11.001

Nomura, R. (2022). Influence of crowd size on home advantage in the Japanese football league. Frontiers in Sports and Active Living, 4, Article 927774. https://doi.org/10.3389/fspor.2022.927774

Oudejans, R. R. D., Verheijen, R., Bakker, F. C., Gerrits, J. C., Steinbrückner, M., & Beek, P. J. (2000). Errors in judging 'offside' in football. Nature, 404(6773), 33. https://doi.org/10.1038/35003639

Pace, A., & Carron, A. V. (1992). Travel and the home advantage. Canadian Journal of Sports Sciences, 17(10), 60-64.

Page, K., & Page, L. (2010). Alone against the crowd: Individual differences in referees' ability to cope under pressure. Journal of Economic Psychology, 31(2), 192-199. https://doi.org/10.1016/j.joep.2009.08.007

Paulauskas, R., Stumbras, M., Coutinho, D., & Figueira, B. (2022). Exploring the impact of the COVID-19 pandemic in Euroleague Basketball. Frontiers in Psychology, 13, Article 979518. https://doi.org/10.3389/fpsyg.2022.979518

Pettersson-Lidborn, P., & Priks, M. (2010). Behavior under social pressure: Empty Italian stadiums and referee bias. Economics Letters, 108(2), 212-214. https://doi.org/10.1016/j.econlet.2010.04.023

Piancastelli, L. S. C., Friel, N., Barreto-Souza, W., & Ombao, H. (2023). Multivariate Conway-Maxwell-Poisson distribution: Sarmanov method and doubly intractable Bayesian inference. Journal of

Computational and Graphical Statistics, 32(2), 483-500. https://doi.org/10.1080/10618600.2022.2116443
Plessner, H., & Haar, T. (2006). Sports performance judgments from a social cognition perspective. Psychology of Sport and Exercise, 7(6), 555-575. https://doi.org/10.1016/j.psychsport.2006.03.007
Pollard, R. (1986). Home advantage in soccer: A retrospective analysis. Journal of Sports Sciences, 4(3), 237-248. https://doi.org/10.1080/02640418608732122
Pollard, R. (2002). Evidence of a reduced home advantage when a team moves to a new stadium. Journal of Sports Sciences, 20(12), 969-973. https://doi.org/10.1080/026404102321011724
Pollard, R. (2006). Home advantage in soccer: Variations in its magnitude and a literature review of the inter-related factors associated with its existence. Journal of Sport Behavior, 29(2), 169-189.
Pollard, R. (2008). Home advantage in football: A current review of an unsolved puzzle. The Open Sports Sciences Journal, 1(1), 12-14. https://doi.org/10.2174/1875399X00801010012
Pollard, R., & Gómez, M. A. (2014). Comparison of home advantage in men's and women's football leagues in Europe. European Journal of Sport Science, 14(S1), S77-S83. https://doi.org/10.1080/17461391.2011.651490
Pollard, R., & Pollard, G. (2005). Long-term trends in home advantage in professional team sports in North America and England (1876-2003). Journal of Sports Sciences, 23(4), 337-350. https://doi.org/10.1080/02640410400021559
Pollard, R., Prieto, J., & Gómez, M. A. (2017). Global differences in home advantage by country, sport and sex. International Journal of Performance Analysis in Sport, 17(4), 586-599. https://doi.org/10.1080/24748668.2017.1372164
Ponzo, M., & Scoppa, V. (2018). Does the home advantage depend on crowd support? Evidence from same-stadium derbies. Journal of Sports Economics, 19(4), 562-582. https://doi.org/10.1177/1527002516665794
Poolton, J., Siu, C. M., & Masters, R. (2011). The home team advantage gives football referees something to ruminate about. International Journal of Sports Science and Coaching, 6(4), 545-552. https://doi.org/10.1260/1747-9541.6.4.545
Price, J., & Wolfers, J. (2010). Racial discrimination among NBA referees. The Quarterly Journal of Economics, 125(4), 1859-1887. https://doi.org/10.1162/qjec.2010.125.4.1859
Prieto, J. (2021). Science mapping: A bibliometric analysis of the home advantage phenomenon in sport. In M. A. Gómez-Ruano, R. Pollard, & C. Lago-Peñas (Eds.), Home advantage in sport: Causes and the effect on performance (pp. 24-30). Routledge. https://doi.org/10.4324/9781003081456-4
Raab, M., Avugos, S., Bar-Eli, M., & MacMahon, C. (2020). The referee's challenge: A threshold process model for decision making in sport games. International Review of Sport and Exercise Psychology, 4(1), 208-228. https://doi.org/10.1080/1750984X.2020.1783696
Ramchandani, G., & Millar, R. (2023). Investigating the "twelfth man" effect in five European domestic football leagues: A COVID-19 induced natural experiment. Journal of Global Sport Management, 8(4), 928-942. https://doi.org/10.1080/24704067.2021.1951614
Reade, J. J., Schreyer, D., & Singleton, C. (2022). Eliminating supportive crowds reduces referee bias. Economic Inquiry, 60(3), 1416-1436. https://doi.org/10.1111/ecin.13063
Ribeiro, L. C., Fonseca, F. S., Costa, G. C. T., Castro, H. O., Santos, P. V. S., & Figueiredo, L. S. (2022). Did the absence of crowd support during the Covid-19 pandemic affect the home advantage in Brazilian elite soccer? Journal of Human Kinetics, 81(1), 251-258. https://doi.org/10.2478/hukin-2022-0047
Ribeiro, H. V., Mukherjee, S., & Zeng, X. H. T. (2016). The advantage of playing home in NBA: Microscopic, team-specific and evolving features. PLoS ONE, 11(3): e0152440. https://doi.org/10.1371/journal.pone.0152440

 © 2024 ARD Asociación Española

Rickman, N., & Witt, R. (2008). Favouritism and financial incentives: A natural experiment. Economica, 75(298), 296-309. https://doi.org/10.1111/j.1468-0335.2007.00605.x

Romanowich, P. (2012). Home Advantage in retractable-roof baseball stadia. Perceptual and Motor Skills, 115(2), 559-566. https://doi.org/10.2466/06.20.23.PMS.115.5.559-566

Rovetta, A., & Abate, A. (2021). The impact of cheering on sports performance: Comparison of Serie A statistics before and during COVID-19. Cureus, 13(8), article e 17382. https://doi.org/10.7759/cureus.17382

Salminen, S. (1993). The effect of the audience on the home advantage. Perceptual and Motor Skills, 76(3_suppl), 1123-1128. https://doi.org/10.2466/pms.1993.76.3c.1123

Sampaio, J., Lago, C., Casais, L., & Leite, N. (2010). Effects of starting score-line, game location, and quality of opposition in basketball quarter score. European Journal of Sport Science, 10(6), 391-396. https://doi.org/10.1080/17461391003699104

Samuel, R. D., Tenenbaum, G., & Galily, Y. (2021). An integrated conceptual framework of decision-making in soccer refereeing. International Journal of Sport and Exercise Psychology, 19(5), 738-760. https://doi.org/10.1080/1612197X.2020.1766539

Sánchez, R., & García-de-Alcaraz, A. (2021). Crowd effects, territoriality and home advantage: A sociological explanation. In M. A. Gómez-Ruano, R. Pollard, & C. Lago-Peñas (Eds.), Home advantage in sport: Causes and the effect on performance (pp. 51-63). Routledge. https://doi.org/10.4324/9781003081456-7

Sánchez, A. J., & Lavín, J. M. (2020). Home advantage in European soccer without crowd. Soccer & Society, 22(1-2), 152-165. https://doi.org/10.1080/14660970.2020.1830067

Santana H. A. P., Bettega, O. B., & Dellagrana, R. A. (2021). An analysis of Bundesliga matches before and after social distancing by COVID-19. Science and Medicine in Football, 5(sup1), 17-21. https://doi.org/10.1080/24733938.2021.1903540

Sapp, R. M., Spangenburg, E. E., & Hagberg, J. M. (2018). Trends in aggressive play and refereeing among the top five European soccer leagues. Journal of Sports Sciences, 36(12), 1346-1354. https://doi.org/10.1080/02640414.2017.1377911

Schwartz, B., & Barsky, S. F. (1977). The home advantage. Social Forces, 55(3), 641-661. https://doi.org/10.1093/sf/55.3.641

Scoppa, V. (2008). Are subjective evaluations biased by social factors or connections? An econometric analysis of soccer referee decisions. Empirical Economics, 35(1), 123-140. https://doi.org/10.1007/s00181-007-0146-1

Scoppa, V. (2021). Social pressure in the stadiums: Do agents change behavior without crowd support? Journal of Economic Psychology, 82, Article 102344. https://doi.org/10.1016/j.joep.2020.102344

Sedeaud, A., De Larochelambert, Q., Schipman, J., & Toussaint, J. F. (2021). The COVID-19 pandemic impact on away and home victories in soccer and rugby union. Frontiers in Sports and Active Living, 3, Article 695922. https://doi.org/10.3389/fspor.2021.695922

Silva, A. C., Amaral, A. S., Facundo, L. A., Wiprich, M. T., Rechenchosky, L., & Rinaldi, W. (2022). Two years of COVID-19 pandemic: How the Brazilian Serie A Championship was affected by home advantage, performance and disciplinary aspects. International Journal of Environmental Research and Public Health, 19(16), Article 10308. https://doi.org/10.3390/ijerph191610308

Smith, R. (2005). Disconnects between popular discourse and home advantage research: What can fans and media tell us about the home advantage phenomenon? Journal of Sports Sciences, 23(4), 351-364. https://doi.org/10.1080/02640410400021633

Sors, F., Grassi, M., Agostini, T., & Murgia, M. (2021). The sound of silence in association football: Home advantage and referee bias decrease in matches played without spectators. European Journal of Sport Science, 21(12), 1597-1605. https://doi.org/10.1080/17461391.2020.1845814

Sors, F., Grassi, M., Agostini, T., & Murgia, M. (2023). The influence of spectators on home advantage and referee bias in national teams matches: Insights from UEFA Nations League. International Journal of Sport and Exercise Psychology, 21(2), 290-305. https://doi.org/10.1080/1612197X.2022.2044367

Souchon, N., Cabagno, G., Rascle, O., Traclet, A., Dosseville, F., & Maio, G. R. (2009). Referees' decision making about transgressions: The influence of player gender at the highest national level. Psychology of Women Quarterly, 33(4), 445-452. https://doi.org/10.1111/j.1471-6402.2009.01522.x

Spitz, J., Put, K., Wagemans, J., Williams, A. M., & Helsen, W. F. (2016). Visual search behaviors of association football referees during assessment of foul play situations. Cognitive Research: Principles and Implication, 1(1), Article 12. https://doi.org/10.1186/s41235-016-0013-8

Staufenbiel, K., Lobinger, B., & Strauss, B. (2015). Home advantage in soccer - a matter of expectations, goal setting and tactical decisions of coaches? Journal of Sports Sciences, 33(18), 1932-1941. https://doi.org/10.1080/02640414.2015.1018929

Steinfeldt, H., Dallmeyer, S., & Breuer, C. (2022). The silence of the fans: The impact of restricted crowds on the margin of victory in the NBA. International Journal of Sport Finance, 17(3), 165-177. https://doi.org/10.32731/IJSF/173.082022.04

Stone, J., Perry, Z. W., & Darley, J. M. (1997). "White men can't jump": Evidence for the perceptual confirmation of racial stereotypes following a basketball game. Basic and Applied Social Psychology, 19(3), 291-306. https://doi.org/10.1207/s15324834basp1903_2

Strauss, B. (2002). The impact of supportive spectator behavior on performance in team sports. International Journal of Sport Psychology, 33(4), 372-390.

Sutter, M., & Kocher, M. G. (2004). Favoritism of agents - the case of referees' home bias. Journal of Economic Psychology, 25(4), 461-469. https://doi.org/10.1016/S0167-4870(03)00013-8

Szabó, D. Z. (2022). The impact of differing audience sizes on referees and team performance from a North American perspective. Psychology of Sport and Exercise, 60, Article 102162. https://doi.org/10.1016/j.psychsport.2022.102162

Terry, P. C., Walrond, N., & Carron, A. V. (1998). The influence of game location on athletes' psychological states. Journal of Science and Medicine in Sport, 1(1), 29-37. https://doi.org/10.1016/S1440-2440(98)80006-6

Tilp, M., & Thaller, S. (2020). Covid-19 has turned home advantage into home disadvantage in the German soccer Bundesliga. Frontiers in Sports and Active Living, 2, Article 593499. https://doi.org/10.3389/fspor.2020.593499

Torgler, B. (2004). The economics of the FIFA football World Cup. Kyklos, 57(2), 287-300. https://doi.org/10.1111/j.0023-5962.2004.00255.x

Ungureanu, A. N., Lupo, C., & Brustio, P. R. (2021). A machine learning approach to analyze home advantage during COVID-19 pandemic period with regards to margin of victory and to different tournaments in professional rugby union competitions. International Journal of Environmental Research and Public Health, 18(23), Article 12711. https://doi.org/10.3390/ijerph182312711

Unkelbach, C., & Memmert, D. (2008). Game-management, context-effects and calibration: The case of yellow cards in soccer. Journal of Sport and Exercise Psychology, 30(1), 95-109. https://doi.org/10.1123/jsep.30.1.95

Unkelbach, C., & Memmert, D. (2010). Crowd noise as a cue in referee decisions contributes to the home advantage. Journal of Sport and Exercise Psychology, 32(4), 483-498. https://doi.org/10.1123/jsep.32.4.483

van Damme, N., & Baert, S. (2019). Home advantage in European international soccer: Which dimension of distance matters? Economics, 13(2019-50), 1-17. https://doi.org/10.5018/economics-ejournal.ja.2019-50

 © 2024 ARD Asociación Española

van de Ven, N. (2011). Supporters are not necessary for the home advantage: Evidence from same-stadium derbies and games without an audience. Journal of Applied Social Psychology, 41(12), 2785-2792. https://doi.org/10.1111/j.1559-1816.2011.00865.x

Vandoni, M., Ferraro, O. E., Gatti, A., Marin, L., Giuriato, M., Silvestri, D., Lovecchio, N., Puci, M. V., & Carnevale Pellino, V. (2022). The role of crowd support on home advantage during COVID-19 restrictions on Italian football competitions: Comparison between 2018-19 and 2020-21 seasons of the Italian Serie A and Serie B Championships. Sports, 10(2), Article 17. https://doi.org/10.3390/sports10020017

van Ours, J. C. (2019). A note on artificial pitches and home advantage in Dutch professional football. Economist, 167(1), 89-103. https://doi.org/10.1007/s10645-019-09332-2

Wallace, H. M., Baumeister, R. F., & Vohs, K. D. (2005). Audience support and choking under pressure: A home disadvantage? Journal of Sports Sciences, 23(4), 429-438. https://doi.org/10.1080/02640410400021666

Webb, T. (2021). The future of officiating: Analysing the impact of COVID-19 on referees in world football. Soccer & Society, 22(1-2), 12-18. https://doi.org/10.1080/14660970.2020.1768634

Webb, T., Dicks, M., Thelwell, R., & Nevill, A. (2018). The impact of referee training: Reflections on the reduction of home advantage in association football. Soccer & Society, 19(7), 1024-1037. https://doi.org/10.1080/14660970.2016.1267626

Weston, M. (2015). Match performance of soccer referees: The role of sport science. Movement and Sport Sciences, 87(1), 113-117. https://doi.org/10.3917/sm.087.0113

Winkelmann, D., Deutscher, C., & Oetting, M. (2021). Bookmakers' mispricing of the disappeared home advantage in the German Bundesliga after the COVID-19 break. Applied Economics, 53(26), 3054-3064. https://doi.org/10.1080/00036846.2021.1873234

Wolfson, S., Wakelin, D., & Lewis, M. (2005). Football supporters' perceptions of their role in the home advantage. Journal of Sports Sciences, 23(4), 365-374. https://doi.org/10.1080/02640410400021567

Wunderlich, F., Weigelt, M., Rein, R., & Memmert, D. (2021). How does spectator presence affect football? Home advantage remains in European top-class football matches played without spectators during the COVID-19 pandemic. PLoS ONE, 16(3): e0248590. https://doi.org/10.1371/journal.pone.0248590

Yi, Q., Gómez, M. A., Liu, H., Gao, B., Wunderlich, F., & Memmert, D. (2020). Situational and positional effects on the technical variation of players in the UEFA Champions League. Frontiers in Psychology, 11, Article 1201. https://doi.org/10.3389/fpsyg.2020.01201

Zeller, R. A., & Jurkovac, T. (1989). A dome stadium: Does it help the home team in the national football league? Sport Place, 3(3), 36-39.

Zimmer, T. E., Snyder, A., & Bukenya, L. (2021). American baseball fans do not influence game outcomes. Economics Bulletin, 41(2), 741-750.

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

REVIEW ARTICLE

Easy interval method, an alternative approach to improve anaerobic threshold speed

Bence Kelemen ✉ *Doctoral School of Sport Sciences. Hungarian University of Physical Education and Sport Sciences. Hungary.*
Ottó Benczenleitner. *Institute of Sports Sciences. Eszterházy Károly Catholic University. Hungary.*
László Tóth. *Department of Psychology and Sport Psychology. Hungarian University of Physical Education and Sport Sciences. Hungary.*
Teacher Training Institute. Hungarian University of Physical Education and Sports Sciences. Hungary.

ABSTRACT

This paper presents the specific training method in distance running developed by the Dutch running coach Herman Verheul and successfully applied in the 1970s, its historical background, its afterlife, and its possible applications. The Verheul method can be traced back to the Stampfl interval method used in the 1960s. It involves the use of shorter (200 and 400 meters) and longer (1000 and later 2000 meters) interval training sessions on a daily basis. The method is characterised by a low intensity of partial distances compared to traditional interval training and a relatively long active recovery period equal to the interval distance. For these reasons, the workouts remain predominantly aerobic, without significant lactic acid accumulation, allowing interval training to be used daily and avoiding over-exertion. The method allows runners to achieve high weekly volumes at high running speeds, crucial for establishing anaerobic threshold speed (vLT2) and economical running movement (RE), essential for successful distance running performance. The easy interval method offers an alternative means of improving anaerobic threshold speed. It may provide a new tool to the recently used sustained tempo runs and the anaerobic threshold intervals that are prevalent today.

Keywords: Distance running, Anaerobic threshold, Interval training.

Cite this article as:
Kelemen, B., Benczenleitner, O., & Tóth, L. (2024). Easy interval method, an alternative approach to improve anaerobic threshold speed. *Scientific Journal of Sport and Performance*, *3*(2), 220-227. https://doi.org/10.55860/SZDQ4880

✉ **Corresponding author.** *Doctoral School of Sport Sciences. Hungarian University of Physical Education and Sport Sciences. Hungary.*
E-mail: bencekelemen95@gmail.com
Submitted for publication January 17, 2024.
Accepted for publication February 19, 2024.
Published March 03, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/SZDQ4880

INTRODUCTION

In recent decades, much literature has been published internationally on the physiological, anthropometric, and morphological factors considered crucial for successful performance in middle and long-distance running (Kovács et al., 2021). Physiological factors that can affect distance running performance include maximal oxygen uptake (VO_{2max}), running economy (RE), the velocity associated with maximal oxygen uptake (vVO_{2max}) (Noakes et al., 1990; Noakes, 2001; Conley & Krahenbuhl, 1980), and anaerobic threshold and associated running velocity (vAt), which are strong predictors of performance (Tjelta et al., 2012). It is essential to consider these factors when assessing an athlete's performance. Since the early 1900s, coaches have developed training methods to improve athletic performance based on empirical observations. There is widespread agreement among coaches and researchers that the development of athletic parameters is influenced by three main factors: training volume, training density, and training intensity. Various studies have shown that the optimal combination of these factors may vary from athlete to athlete, depending on their level of competition. There may also be differences in the training tools coaches use to achieve specific physiological adaptations.

Research objectives

This study examines the distance running training method developed by Dutch coach Herman Verheul in the 1970s, its historical antecedents, and its aftermath. It also aims to compare this method with contemporary training methods and to evaluate its potential benefits and applications.

Historical overview

The interval method developed by Dr Woldemar Gerchler is widely regarded as a breakthrough in training techniques. In the late 1930s, Dr. Gerchler and the eminent cardiologist Dr. Herbert Reindel conducted experiments that led to the development of this method. The training regimen involved runners performing short, fast repetitions of 100, 150, or 200 meters, often up to 40-80 times in a single session. The pace of the repetitions was such that the participants could reach a heart rate of 180 beats per minute after the run. The next faster repetition was started when the heart rate had returned to 120 bpm. It is widely recognised that the rest and recovery period between runs is the most essential part of the exercise, during which the heart adapts, strengthens, and enlarges. If the heart rate did not decrease to 120 beats per minute within 90 seconds of the previous run's conclusion, the exercise was considered too strenuous and had to be modified. Gerschler's interval training has been found to result in rapid performance improvements. This is due to the strengthening of the heart, which leads to a quicker return to a resting heart rate of 120 beats/min and reduced recovery times. The length of rest periods was reduced to increase the difficulty of the training, and the number of partial distances covered was increased, rather than the pace of fast sections (Cobley, 2011a).

During the 1940s and 1950s, interval training gained popularity as the primary method for training distance runners worldwide. The Czech Olympic champion, Emil Zatopek, was known for his rigorous training routine, which included multiple sets of 200 and 400 meters at varying speeds, with a 1-minute 200-meter jog between faster sections. According to Billat (2001), Zatopek eventually increased the number of 400-meter repeats to 50-60. Another significant contributor to the method was the accomplished Hungarian coach, Mihály Iglói. He achieved numerous successes in his home country, training athletes such as Sándor Iharos, László Tábori, and István Rózsavölgyi, as well as in the United States, where he coached Bob Schul, the 1964 Olympic champion in the 5000m, and also in Greece. Iglói's training regime primarily consisted of running short distances in various sets, with up to 14 weekly training sessions lasting up to 1-2 hours. During the intervals, runners were instructed to run at various sub-maximal speeds with active rest periods. The training was tailored to the athlete's current daily condition and movement. The longer intervals were primarily performed at high intensity, at race pace, with limited repetitions and extended rest periods (Wilt, 1959).

The use of longer repeats (800 to 2400 meters) and the progression of intervals throughout the season is attributed to Franz Stampl, an Austrian who achieved excellent results in the second half of the 1950s and 1960s. The Stampl system was introduced in England by Chris Chataway and Chris Brasher and in Australia by Merv Lincoln and Ralph Doubell. It is closely associated with Roger Bannister and the first 4-minute mile. The athletes' training methods were similar to those of other elite athletes in the 1950s. The training plan consisted of various distances of 10x400m, 6x800m, and 4x1200m on track 4-5 times a week, plus gymnastics and 60-90 minutes of Fartlek running during the preseason. The foundation was laid in November, and the interval paces were gradually increased by 2 seconds per lap per month until the target race pace was reached during the summer. The training for distance running, which consisted of almost weekly and daily interval training, was modified from the 1970s onwards by Arthur Lydiard's 'marathon method' due to the success of New Zealand runners (Cobley, 2011b).

THE VERHEUL METHOD

The Verheul method was confidently developed by Dutch trainer Herman Verheul (b. 1932) in the second half of the 1960s. Like the school of Franz Stampfl, the method mainly consists of shorter (200 and 400 meters) and longer (1000 meters) daily intervals with equal lengths of active rest. Verheul's speciality, however, was to ask his runners to run increasingly slower intensities during the faster sections based on his empirical observations. The coach found that slower paces yielded better results interestingly. The runners could improve their performance by emphasising a loose, easy, and flexible running motion during partial distances. The method does not include long, sustained endurance runs, which result in a slow and cumbersome running motion. The runners were only given a hard, sustained, high-intensity workload during races, but these races were run almost weekly. These were mainly cross-country races, indoor track races of various lengths in winter and outdoor track races in summer.

Verheul followed the guiding principle of Hungarian coach Mihály Iglói, who believed that athletes should never train harder than they recover the next day. The training pace was, therefore, very individual, and the interval times were adapted to the athlete's current condition, with no tables used to set the training pace and little attention paid to heart rate data. He observed and interviewed each athlete and drew conclusions from that runner's recent race results. However, as a guideline, he made the following suggestions for interval paces: the fastest pace for the 200 m interval should be at 3 km race pace or, at maximum, at 1500 m race pace, the fastest pace for the 400 m interval should be at 5 km race pace, and the fastest pace for the 1000 m interval should be at 15 km or half-marathon race pace (or 1-hour race pace).

The number of repetitions was never increased above 15x200m, 10x400m and 6x1000m; the increase in workload was mainly due to the switch to faster paces and faster running in races, as well as a second and third 6×1000m training sessions a week during the winter base period. Reduced part distance numbers were recommended for young, novice and older (masters) runners and athletes returning from injury. A typical "*reduced program*" training session was 12×200 m, 8×400 m and 4×1000 m. Between the sub-distances, the athletes rested for a distance equal to the distance run (200 m for 200 m, 400 m for 400 m and 1000 m for 1000 m), walking for 10-20 seconds after the fast sections and before the next interval to give the muscles an additional opportunity to recover. In between the walking periods, the runners jogged at a light jogging pace (in the case of Klaas Lok, this was 5 min/km). These deliberately long active recovery periods were designed to lighten the load and to ensure that the training was predominantly aerobic, maintaining efficient,

 © 2024 ARD Asociación Española

relaxed running during the intervals. Verheul, like Ernest van Aaken, another successful German coach of his time who emphasised endurance training, believed that heart rates above 150 beats per minute (around 85% MHR, or close to the anaerobic threshold) during exercise should be avoided and were more harmful than beneficial. The weekly competitions were, of course, an exception to this. After the races, he emphasised recovery not based on sustained easy runs but on relaxed 200-metre intervals.

In addition to interval training, the other two elements of the training program were strengthening and gymnastic exercises, which were part of the warm-up and were performed once a week in the hall during the winter, and Fartlek running, which was also performed during the winter preparation period. The latter was carried out on Saturdays in a wooded area and consisted of an average of 16 mixed-paced runs of varying lengths (aerobic and anaerobic) and gymnastic and strengthening exercises, lasting between 75 minutes and 1 hour 45 minutes in total. The easy interval sessions were preceded by 10-15 minutes of jogging, short gymnastics, and 4-6x80m of acceleration running; at the end, the runners reached a speed of 1500-800m. This approach has won several national championships with his club and has seen his athletes set national records. His most successful students were Ad Buijs (10,000m- 29:11), Joost Borm (1500m- 3:38.3; 2000m- 5:01.27) and Klaas Lok (1500m-3:38.8; 2000m- 5:03.90; 3000m-7:51.4; 5000m- 13:30.3; 10,000m- 28:24.7) (Lenferink, 2007).

Table 1. Typical training week in the Verheul method during the competition period.

Day	Training session
Monday	10x400m
Thursday	6x1000m
Wednesday	15x200m
Thursday	6x1000m
Friday	10x400m
Sunday	Rest
Saturday	Race, or Fartlek with anaerobic paces

THE EASY INTERVAL METHOD

The Easy Interval Method was applied successfully by several Dutch coaches and runners after the 1970s, building on the foundations laid down by Herman Verheul. Klaas Lok, Verheul's most successful runner, is a prominent advocate of the method. During his racing career, Lok experimented with the method and increased the workload. He later applied these innovations in his coaching work and explained them in a book published in Dutch and English (Lok, 2019). The coach has suggested incorporating long interval training several times a week, with up to 4-5 sessions per week during the preseason and increasing the length and number of intervals. For elite racers, completing up to 8 sets of 1000 meters with 800-meter rest intervals or 4-5 sets of 2000 meters at marathon race intensity with 1000-meter rest intervals on a weekly or bi-weekly basis is often recommended. In addition, the author suggests 100-meter intervals similar to Gercheler's for middle-distance runners. These intervals can supplement traditional easy interval training sessions (6-8 repeats) or as a stand-alone workout (e.g. 20x100m with 100m rest at middle-distance race pace). These intervals aim to develop coordination at race pace and an economical running movement.

Additionally, the author mentions that he used two training sessions a day during their career. These intervals could consist of either brisk 7-10 km runs at marathon pace in the morning with half-minute changes of pace every 5-10 minutes or easy intervals twice a day (longer intervals in the morning and shorter ones in the afternoon). During the spring race-specific period before the summer track season, it is recommended to incorporate traditional anaerobic interval work every 7-10 days to prepare the athlete for competition fatigue and help develop anaerobic skills (Lok, 2019).

Table 2. Easy Interval sessions (* traditionally not included in the Verheul method).

Interval	Race pace	Recovery distance
20x100m*	1500m-800m	100m
15x200m	3000–1500m	200m
10x400m	10.000–5000m	400m
6-(8-10)x1000m	Half Marathon- 15km	800-1000m
4-5x2000m*	Marathon	1000m

DISCUSSION

The research of Casado et al. (Casado et al., 2021) shows that the development of aerobic skills primarily characterises the preparation of modern elite distance runners. This is carried out with a high volume (70-80% of the weekly training volume of 120-180 kilometres) of easy, continuous runs below the aerobic threshold (vLT1) and with tempo runs that develop the anaerobic threshold speed (vLT2), and also the use of short (>800 meters) intervals at close to racing speed is essential (Kelemen et al., 2023a). The purpose of the latter training device is primarily to maintain the coordination and anaerobic endurance associated with competition speed during the base period (Haugen et al., 2022). Athletes only start using the more extended, aerobic capacity-developing (VO_{2max}), competition-specific intensive interval training during the 4-8 week conditioning period before the competition season. In parallel with this finding, numerous empirical descriptions and articles in the literature were published, in which elite long-distance runners during their preparation performed so-called "*Sub-Threshold runs*" between their aerobic and anaerobic threshold (vLT1 and vLT2) several times a week (2-4, or even more often) (Tjelta & Enoksen, 2001; Enoksen et al., 2011; Tjelta, 2016, Casado, Hanley & Ruíz-Perez, 2020; Casado et al., 2022). These efforts below the anaerobic threshold cause less central and peripheral fatigue than the intensities performed at the anaerobic threshold (vLT2). At these still relatively fast paces, a higher weekly volume can be achieved without overtraining, thus "*pushing the anaerobic threshold speed up from below*" (Casado et al., 2023). In the 1970s and 1980s, athletes often performed these "*spontaneously*" as progression runs during their sustained daily runs on the days between the traditional interval training sessions. At that time, they started running at a leisurely aerobic regeneration pace, then as they warmed up as the run progressed, the pace increased, and in the last 20-30 minutes of the run, they ran at marathon and half-marathon pace. Examples of this are the British Steve Cram (Poole, 1995), the Norwegian world record runner Grete Waitz (Tjelta et al., 2014), the 1500m world record holder Hicham El-Guerrouj (Bakken, 2001), or the training of Kenyan athletes (Billat et al., 2003). Nowadays, these Sub-Threshold workouts are carried out according to plan, structured on certain days of the week, with precise intensity monitoring. In contrast to sustained runs, elite competitors increasingly use the interval format, during which the effort can be controlled much better (Tjelta, 2013). A great example of this method is the specific approach developed by Norwegian runners in the 2000s, which is getting the most attention today (Kelemen et al., 2023b). The peculiarity of this system is the use of so-called "*Double-Threshold days*". The runners perform interval training a total of 4 times a week, twice on one training day (morning and afternoon) below the anaerobic threshold (< 4 mmol/L blood lactate). During this training, 10-12 kilometres are covered each session (workouts are typical: 25x400m; 10x1000m; 5x2000m), with short rest periods of 0.5-1 minutes. Between partial distances, the intensity is kept in the appropriate zone with the help of a lactate meter and heart rate monitors. By observing these zones, they can cover up to 30-40 kilometres per week at relatively high speeds. In addition to the high-volume easy, sustained aerobic runs and mentioned anaerobic-threshold intervals, during the base period, runners also perform one weekly exercise producing higher lactate values (~8 mmol/L) in the form of faster but shorter interval training (ex.: 2x10x200 meters uphill), and short alactic sprints (Casado and et al., 2023; Kelemen et al., 2022; Bakken, 2021).

CONCLUSIONS AND PRACTICAL APPLICATIONS

The Easy Interval Method, developed by Herman Verheul and later refined by Klaas Lok, is a potential alternative for improving anaerobic threshold speed, a crucial value for successful distance running performance. Intensity is challenging to control in sustained, paced runs, and there is a risk of over-exertion if they are not performed correctly. For less fit runners, the speed and biomechanics of endurance run lasting between 20 and 60 minutes are often outside the race pace. Additionally, the anaerobic-threshold intervals commonly used today and measured by lactate levels require devices (lactate monitor and strips), which are not always available and are expensive. Longer, easy interval training sessions, lasting 1-2 km, are predominantly aerobic due to their low intensity and relatively longer active rest periods. As a result, they do not lead to significant blood lactate uptake and can be performed multiple times a week (2-5). In this way, achieving high weekly volumes around the anaerobic threshold is possible, similar to elite athletes. This conditions the transitional IIb muscle fibres for aerobic energy production (Plotkin et al., 2021), which can lead to excellent distance running performances. The shorter, predominantly aerobic 100-200-400 m easy intervals can help develop an economical running motion at race speed. Easy intervals should be supplemented with a traditional high-intensity interval workout every 7-10 days in the base period to maintain anaerobic fitness and with short alactic sub-maximal sprints (lasting 10-15 seconds). In the 4-6 weeklong pre-competition period, longer, race-specific sessions with higher lactate values are recommended 1-2 times weekly to prepare the runners for race fatigue. Due to their less strenuous nature, easy intervals during the race period can also provide an alternative way to maintain the endurance gained during the base period.

AUTHOR CONTRIBUTIONS

Bence Kelemen developed the theoretical formalism, conducted a systematic review of the research and summarised the data. Authors Bence Kelemen and Ottó Benczenleitner contributed to the final version of the manuscript. László Tóth supervised the project.

SUPPORTING AGENCIES

Supported by the ÚNKP-2023 New National Excellence Program of the Ministry for Innovation and Technology from the source of the National Research, Development and Innovation Fund.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Bakken, Marius (2001). Maroccan training - El Guerrouj. Retrieved from [Accessed February 21, 2024]: https://www.mariusbakken.com/training-corner/maroccan-training-el-guerrouj.html

Bakken, Marius (2021) The Norwegian model. Retrieved from [Accessed February 21, 2024]: http://www.mariusbakken.com/the-norwegian-model.html

Billat VL, Lepretre PM, Heugas AM, Laurence MH, Salim D, Koralsztein JP. (2003) Training and bioenergetic characteristics in elite male and female Kenyan runners. Med Sci Sports Exerc. 2003;35(2): 297-304. https://doi.org/10.1249/01.MSS.0000053556.59992.A9

Brandon L. J. (1995). Physiological factors associated with middle distance running performance. Sports medicine (Auckland, N.Z.), 19(4), 268-277. https://doi.org/10.2165/00007256-199519040-00004

Casado, A., Foster, C., Bakken, M., & Tjelta, L. I. (2023). Does Lactate-Guided Threshold Interval Training within a High-Volume, Low-Intensity Approach Represent the "Next Step" in the Evolution of Distance Running Training? International Journal of Environmental Research and Public Health, 20(5), 3782. MDPI AG. https://doi.org/10.3390/ijerph20053782

Casado, A., González-Mohíno, F., González-Ravé, J. M., & Foster, C. (2022). Training Periodization, Methods, Intensity Distribution, and Volume in Highly Trained and Elite Distance Runners: A Systematic Review. International Journal of Sports Physiology and Performance, 17(6), 820-833. https://doi.org/10.1123/ijspp.2021-0435

Casado, A., Hanley, B., & Ruiz-Pérez, L. M. (2020). Deliberate practice in training differentiates the best Kenyan and Spanish long-distance runners. European journal of sport science, 20(7), 887-895. https://doi.org/10.1080/17461391.2019.1694077

Casado, A., Hanley, B., Santos-Concejero, J., & Ruiz-Pérez, L. M. (2021). World-Class Long-Distance Running Performances Are Best Predicted by Volume of Easy Runs and Deliberate Practice of Short-Interval and Tempo Runs. Journal of Strength and Conditioning Research, 35(9), 2525-2531. https://doi.org/10.1519/JSC.0000000000003176

Cobley, J. (2011a). Coach Profile: Woldemar Gerschler. Retrieved from [Accessed February 21, 2024]: https://racingpast.ca/john_contents.php?id=129

Cobley, J. (2011b). Profile: Franz Stampfl. Retrieved from [Accessed February 21, 2024]: https://racingpast.ca/john_contents.php?id=143

Conley DL and Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc 1980; 12: 357-360. https://doi.org/10.1249/00005768-198025000-00010

Foster, Carl & Daniels, Jack & Seiler, S. (2007). Perspectives on Correct Approaches to Training.

Haugen T, Sandbakk Ø, Seiler S, Tønnessen E. (2022). The Training Characteristics of World-Class Distance Runners: An Integration of Scientific Literature and Results-Proven Practice. Sports Med Open. 2022 Apr 1;8(1):46. https://doi.org/10.1186/s40798-022-00438-7

Kelemen, B., Benczenleitner, O., & Tóth, L. (2023b). The Norwegian double-threshold method in distance running: Systematic literature review. Scientific Journal of Sport and Performance, 3(1), 38-46. https://doi.org/10.55860/NBXV4075

Kelemen, B., Benczenleitner, O., Gyimes, Z., & Toth, L. (2023a). Polarized training intensity distribution in distance running: A case study of the 2021 Olympic long-distance runner. Sustainability and Sports Science Journal, 2(1), 58-66. https://doi.org/10.61486/CKLI8600

Kelemen, Bence és Benczenleitner, Ottó és Tóth, László (2022) A norvég állóképességi modell közép- és hosszútávfutásban: Szisztematikus irodalmi áttekintés = The Norwegian Endurance Model in Middle and Long-Distance Running: A Systematic Review of the Literature. Magyar Sporttudományi Szemle = Hungarian Review of Sport Science, 23 (4). pp. 19-25. ISSN 1586-5428.

Kovács, B., Kóbor, I., Sebestyén, Ö., & Tihanyi, J. (2021). Longer Achilles tendon moment arm results in better running economy. Physiology International, 107(4), 527-541. https://doi.org/10.1556/2060.2020.10000

Lenferink, Herman (2007). The Verheul Method. Retrieved from [Accessed February 21, 2024]: https://avphoenix.nl/topsport/trainingsmethoden/de-verheul-methode/

Lok, K. (2019). Easy Interval Method, The Choir Press; Updated December 2022 ed. edition (July 20, 2019).

 © 2024 ARD Asociación Española

Midgley, A. W., McNaughton, L. R., & Jones, A. M. (2007). Training to enhance the physiological determinants of long-distance running performance: Can valid recommendations be given to runners and coaches based on current scientific knowledge? Sports medicine (Auckland, N.Z.), 37(10), 857-880. https://doi.org/10.2165/00007256-200737100-00003

Noakes T. Physiological capacity of the elite runner. In: Bangsbo J and Larsen HB (eds) Running and Science: an interdisciplinary perspective. Copenhagen: Institute of Exercise and Sports Sciences, University of Copenhagen, Munksgaard, 2001, pp.19-47.

Noakes, T. D., Myburgh, K. H., & Schall, R. (1990). Peak treadmill running velocity during the VO2 max test predicts running performance. Journal of Sports Sciences, 8(1), 35-45. https://doi.org/10.1080/02640419008732129

Plotkin, D. L., Roberts, M. D., Haun, C. T., & Schoenfeld, B. J. (2021). Muscle Fiber Type Transitions with Exercise Training: Shifting Perspectives. Sports (Basel, Switzerland), 9(9), 127. https://doi.org/10.3390/sports9090127

Poole, N. (1995). How Steve Cram Trains. British Milers Club Journal, 1995 Spring, p. 6-10.

Tjelta, L. I., Tønnessen, E., & Enoksen, E. (2014). A Case Study of the Training of Nine Times New York Marathon Winner Grete Waitz. International Journal of Sports Science & Coaching, 9(1), 139-158. https://doi.org/10.1260/1747-9541.9.1.139

Tjelta, L.I. (2013). A Longitudinal Case Study of the Training of the 2012 European 1500m Track Champion. International Journal of Applied Sports Sciences, pp. 25, 11-18. https://doi.org/10.24985/ijass.2013.25.1.11

Tjelta, L.I., Enoksen, E. (2001). Training volume and intensity. Running and Science- in an Interdisciplinary Perspective, 2001, 149-177. Publisher: University of Copenhagen

Tjelta, Leif I. (2016). Review article The training of international level distance runners Leif Inge Tjelta University of Stavanger, Department of Education and Sports Science, N-4036, Stavanger, Norway E-mail: leif.i.tjelta@uis.no International Journal of Sports Science & Coaching, 11(1), Jan/Feb 2016. Accepted for publication, 27.03.2015. International Journal of Sports Science & Coaching. 11. https://doi.org/10.1177/1747954115624813

Tjelta, Leif Inge & Rønning Tjelta, Asle & Dyrstad, Sindre. (2012). Relationship between Velocity at Anaerobic Threshold and Factors Affecting Velocity at Anaerobic Threshold in Elite Distance Runners. International Journal of Applied Sports Sciences. 24. 8-17. https://doi.org/10.24985/ijass.2012.24.1.8

Wilt, F. (1959). How they Train. Half Mile to Six Mile. Track & Field News. First Edition (January 1, 1959) p. 64.

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Mechanical differences between three block jump approaches in NCAA DII college volleyball players

Djuly Schmorantz . *Barry University. Miami, United States of America.*
Tal Amasay. *Barry University. Miami, United States of America.*
Nataniel Boiangin. *Barry University. Miami, United States of America.*
Claire Egret. *Barry University. Miami, United States of America.*

ABSTRACT

The purpose of the study was to examine the kinematics and kinetics differences between three common block approaches used in volleyball games: (1) shuffle block, (2) chicken wing block, and (3) swing block, from a fixed distance of 1.8 m. Ten female collegiate volleyball players from NCAA DII participated in the study. They performed, in a randomized order, a total of 18 blocks equally distributed among the three block types. Noraxon MyoResearch 3 software was used to analyze the block approaches. The statistical analysis was performed by running a Repeated Measurement ANOVA on Jamovi statistical software 2.3.24. The results showed that there was a significant main effect for time to take off, jump height, max knee flexion angles, peak power, relative peak power, net impulse, reactive strength index, max rate of force development, peak force, and relative peak force between the three types of blocks ($p < .05$). While max valgus knee angles and max flexion hip angles did not show any effect ($p > .5$). To cover a distance of 1.8m, it was clear that shuffle block was the weakest option for good block performances, while chicken wing and swing blocks were similar in many aspects. Both chicken wing and swing blocks can be used to elevate the block effectiveness of volleyball players compared to shuffle block.

Keywords: Performance analysis, Kinematics, Kinetics, Effectiveness, Shuffle block, Chicken wing block, Swing block.

Cite this article as:
Schmorantz, D., Amasay, T., Boiangin, N., & Egret, C. (2024). Mechanical differences between three block jump approaches in NCAA DII college volleyball players. *Scientific Journal of Sport and Performance*, *3*(2), 228-237. https://doi.org/10.55860/KIUU6271

Corresponding author. *Barry University. Miami, United States of America.*
E-mail: djuly.schmorantz@mymail.barry.edu
Submitted for publication January 17, 2024.
Accepted for publication February 19, 2024.
Published March 04, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/KIUU6271

INTRODUCTION

One of the most difficult skills to be performed in volleyball is the blocking skill (Patsiaouras et al., 2011). There are various approaches to executing a block in volleyball, with the primary intention of intercepting the opposite team's attack, or dampening (i.e., slowing down) the attack of the opposing team (Alexander, 2012). The action of blocking is a defensive technique that involves a lot of tactics and game reading ability (Patsiaouras et al., 2011). The demand for physical excellence, as well as talent in volleyball has been increasingly sought after, making attacks and jump serve become even more aggressive. Consequently, the execution of these offensive skills has also dramatically increased the importance of the block during game (Braakhuis, 2016).

The main pattern of movement that drives the athlete's success in block skill is the ability to jump (Gollhofer and Bruhn, 2003). Jump movement is a multi-joint action which requires coordination of both lower limbs and upper limbs, summating forces to produce the desired movement outcomes (Mosier et al., 2019). High-performance volleyball athletes, who shows advanced physical development, typically have great vertical jump capacity; thus, being able to penetrate the net with their arms and cover a sufficient area to block the attack and score directly with this movement (Cabarkapa et al., 2020).

Researchers have been trying to identify which volleyball block approach is more effective and in which scenario; however, as the blocking action is an open skill, where external factors influence performance and different approaches can be used, the results are still very abstract (Lobietti, 2009). The success of a block depends on positioning, timing, and movement. In other words, the current description for the most effective block is one that is executed with the following criteria: the right lateral displacement in the shortest time, timing of a fast jump, the right height, great arm penetration, and hand angulation (Lobietti, 2009). On the other hand, the efficiency of blocking is still low (Scates, 1972, as cited in Buekers, 1991). For instance, one of the factors why blocks have low efficiency is because blocking requires a high demand of decision-making ability; thus, making it harder to master this skill in a short timeline (Buekers, 1991). Coaches at the higher volleyball levels cannot wait for the athletes to gain experience. Therefore, to solve this dilemma, of developing "*game reading skill*" ability more efficiently, coaches prepare their teams by organizing techniques to achieve the ideal blocking style (Patsiaouras at el, 2011).

A fast lateral approach is a key factor for block effectiveness. For effective lateral movement analysis, Buekers (1991), analyzed players' approaches moving from the middle of the court to the side of the court (3 m distance) focusing on the timing of feet movement and hands arriving over the net. According to Buekers (1991), who looked at female players from first and second Belgium national league, the fastest approach for a lateral displacement was the running step (crossover approach, mean time of 1,899 ms), and the one that took the longer time was the slide step (shuffle approach, mean time of 2,013 ms). Buekers (1991) suggested that the technique used must vary according to the distance the player must cover when blocking. Specifically, the slide step is more effective if the player must cover short distances (less than 1.8 m) as the player can keep the body facing the net consuming less time to block. While in longer distances (more than 1.8 m) the most recommended block approach is the crossover approach.

When evaluating arm movement effectiveness in blocking, it was found that the arms motion affected the speed of the previously mentioned lateral movement footwork, as well as the jump height performance (Neves et al., 2011). For instance, Neves and colleagues (2011) compared three arms movement techniques with the crossover step. Traditional block keeping a stationary arm position with hands about shoulder level, chicken wing block keeping elbows on 90° while making the arms swing movement, and swing block with a typical counter-jump motion with elbows extended during the swing. It was found that the traditional block did not produce any advantages, while the other two techniques produced different advantages. The chicken wing block technique produced quicker takeoff movement and hands over the net, while the swing block technique resulted in a higher jump capacity and greater arm penetration (Neves et al., 2011). Even with these findings, there is still lack of clarification of the effectiveness of combining arms motion and footwork approaches within the same distance. More research is needed comparing the mechanical components of the different approaches used within the same lateral displacement.

The purpose of the study was to examine the kinematics and kinetics differences between three common block approaches used in volleyball games: (1) shuffle block, (2) chicken wing block, and (3) swing block, from a fixed distance of 1.8 m. A combination of two footwork approaches and three arms motions were investigated. The different footwork approaches were crossover (chicken wing and swing blocks), and lateral shuffle steps (shuffle block) and the arms motions were stationary arms (shuffle), arms swing with elbows flexed at 90 degrees (chicken wing), and arms swing with full elbows extension (swing).

MATERIAL AND METHODS

Participants

Ten female NCAA DII collegiate level participated in the study (mean ± SD); age 21.8 ± 1.9 years; height 179.0 ± 5.0 cm; body mass 72.2 ± 7.6 kg; body fat percentage 22.3 ± 3.2%; playing experience 10.5 ± 2.8 years, see Table 1. The study was approved by the IRB of the University and all participants signed a consent form before participating in the study. Once consent was acquired, participants were asked to fill out a brief demographic questionnaire. The questionnaire included questions about previous injuries to the lower and upper body for the past year that could compromise performance of any type of block jump, their experience background in competitive volleyball, and strength and conditioning training experience. Inclusion criteria included being an NCAA DII college player with a minimum of four years of volleyball experience and at least one year at college level.

Table 1. Demographic information.

	Age	Height (m)	Weight (kg)	Body Fat %	Years of Experience
N	10	10	10	10	10
Mean	21.80	1.79	72.21	22.31	10.50
Median	21.00	1.78	71.75	23.05	10.00
Standard deviation	1.87	0.05	7.55	3.19	2.80
Minimum	19	1.73	56.40	15.90	7
Maximum	25	1.88	82.60	26.20	16

Measures

Kinematic data were collected using eight Noraxon MyoMotion inertial measurement units (IMUs) (Noraxon MyoMotion, Noraxon USA Inc.), and kinetic data were collected using two AMTI force plates (Boston, MA, USA), and variables were calculated using the MyoForce software (Noraxon MyoForce, MyoForce USA Inc). The sensors were placed on the participant lower body symmetrically based on Noraxon lower body model. The sensors placement location was on the feet (upper foot slightly below the ankle), shanks (front and slightly medial area along the tibia), thighs (frontal and distal portion), pelvic (body area of sacrum), and the last one on upper thoracic (right below C7, in line with spine column). The data analysis was done using the MyoResearch system using Noraxon MyoResearch 3 software (Noraxon MR3 3.20.08).

 © 2024 ARD Asociación Española

Procedures

Warm Up: Once all forms were completed, eligible participants' height, weight, and % body fat were collected before the actual data collection session. Subsequently, participants started with five minutes of general warm-up on a cycle ergometer at a pace of 50 RPM and 1 Kp resistance, followed by five minutes of specific dynamic warm-up for lower body. The specific dynamic warm-up included one set of 10 repetitions of high knees, butt kicks, squats, side lunges (five each side), high knees, and power skip. After the warm-up, the participants were instructed about the desired movements for each jump block approach, and they finished by practicing the three different block jump approaches, at least two trials of each block type for both directions (left and right), with a total of 12 jumps. Participants had at least 5 min rest before the data collection.

Block Jump Session: Athletes performed three trials of each block jump approach from each direction, for a total of 18 block jumps. After each jump the participant had at least 30 s rest interval and at least 2 min break between block jump type and direction, to prevent fatigue effects between jumps. The order of the blocks type and direction were randomized. The block types were shuffle block, chicken wing block, and swing block. The shuffle block is a side steps with toes pointing towards the net the whole time, hand at shoulder level, and no arms swing at all. In the chicken wing block the participant started first by lateral stepping with the leg of the same direction of the movement, foot parallel to the net, then second step crossing the other leg, and finishing the third step in a base with feet facing the net at shoulder width apart, there is an arm swing, but elbows kept flexed at 90° max. The swing block has the same footwork as the chicken wing block, but with arms extended during the arms swing motion. All three movements ended with vertically jumping and extending arms overhead touching the target (ball). The participant started 1.8 m to the right and to the left of the two AMTI force plates. The players started in a ready position to block (feet shoulder width apart, bent knees, and palms facing forward at shoulder level). The participants were instructed on the side and the type of block they would perform before each trial. When the participant was ready to start the test, the researcher instructed the participant to touch the ball with both hands, simulating a block, as fast as possible through a verbal command of 'ready, go'. If the participant did not perform the correct blocking technique the participant had to repeat the trial. The criteria for trial success were (i) not crossing legs during lateral movement on shuffle block type, (ii) keeping hands at hip level or upper the hip on chicken wing block, and (iii) fully elbow extension when hands are down and going behind the back during the swing block (iv) jumping from and landing on the force plates(v) participants had to touch the ball with both hands. Target was set at specific height and distance from the force plate to simulates a real blocking situation, at a vertical distance of 2.34 m and anterior distance of 40 cm, from the force plates. The target height location was estimated based on the net height which is 2.24 m plus the center of volleyball height which 10 cm the horizontal distance of the target was based on the estimated distance of the player from the net which is 20 cm plus 20 cm for forearm overall penetration over the net. Testing was completed once 18 successful trials were obtained.

Data reduction and analysis

The independent variable was block approach type. The dependent variables for this study were shortest time to takeoff, jump height, max knee valgus angle, max knee and hip flexion angles, peak power, relative peak power, peak force, relative peak force, net impulse (NI), reactive strength index (RSI), and max rate of force development. The best of three jump trials, meaning the fastest time to takeoff of each block type and direction was selected for further analysis. Vertical jump height and RSI for all blocks approaches were derived from net impulse. The time to take off was identified from the instant of the 'go' command and the moment in which the player's feet left the force plates. For peak power and angles variables, the 'loading leg' (the first one touching the force plate in each approach) was chosen for the analysis. The angles were calculated based on the maximum change in angular position, with respect to the participant calibration position.

Descriptive statistics (mean ± SD) were calculated for each variable observed in this study. Repeated measure analysis of variance (ANOVA) was used to determine variations between the three different approaches followed by Post Hoc Pairwise Comparisons using Tukey test correction. Mauchly's test of sphericity was used to test whether variances of differences between conditions are equal or not. The significance was set a priori to $p < .05$ and confidence-interval of 95%, using Jamovi statistical software (version 2.3.24).

RESULTS

A randomized block of repeated measures ANOVAs revealed significant main effects between the three different approaches in three kinematics variables ($p < .01$) and all kinetics variables ($p < .01$).

Kinematics variables

Time to Take Off (s): There was a significant main effect in time to take off between the three block jump approaches, ($F_{2,38} = 7.46$, $p = .002$, $\eta^2 = 0.14$). Tukey Test revealed shuffle block was significant slower than swing block by 0.09s and chicken wing block by 0.12s, $p < .05$. No significant difference was found between 'chicken wing' and 'swing' approaches, $p > .05$. See Table 2.

Jump Height (cm): There was a significant main effect in jump height variable between the three block jump approaches, ($F_{2,38} = 9.5$, $p < .001$, $\eta^2 = 0.15$). Tukey Test revealed chicken wing block jump height was significantly higher than shuffle block jump height by 2.8cm, $p < .05$. Swing block jump height was also higher than shuffle block by 3.3cm, $p < .001$. No significant difference was found in the jump height between chicken wing and swing blocks, $p > .05$. See Table 2.

Table 2. Kinematic variables.

	Shuffle Block	**Chicken Wing Block**	**Swing Block**
Time to Take off (s)	1.73 ± 0.03	1.61 ± 0.03	1.64 ± 0.03
Jump Height (cm)	25.43 ± 0.86	28.21 ± 0.78	28.73 ± 0.68

Note: mean ± standard deviation.

Max Flexion Knee Angle (degree): There was a significant main effect in max knee flexion angle between the three block jump approaches, ($F_{2,38} = 36.85$, $p < .001$, $\eta^2 = 0.38$). Tukey Test revealed that chicken wing block max knee flexion angle (72.26 ± 1.34°) was significantly higher than shuffle block max knee flexion angle (62.11 ± 1.13°), $p < .001$. Chicken Wing block max knee flexion angle was significantly higher than swing block max knee flexion angle (68.64 ± 1.24°), $p < .001$. Swing block max knee flexion angle was significantly higher than shuffle block max knee flexion angle, $p < .001$. See Figure 1.

Max Valgus Knee Angles (°): There was no significant main effect in max valgus knee angle between the three block jump approaches, ($F_{2,38} = 2.81$, $p = .07$, $\eta^2 = 0.04$). The average means of shuffle block approach was 11.91 ± 1.8°, chicken wing block 15.65 ± 2.04°, and swing block 15.19 ± 1.72°. See Figure 1.

Max Flexion Hip Angle (degree): There was no significant main effect in max hip flexion angle between the three block jump approaches, ($F_{2,38} = 0.5$, $p = .6$, $\eta^2 = 0.01$). The average means of shuffle block approach was 65.43 ± 1.5°, chicken wing block 66.04 ± 2.17°, and swing block 63.89 ± 1.72°. See Figure 1.

 © 2024 ARD Asociación Española

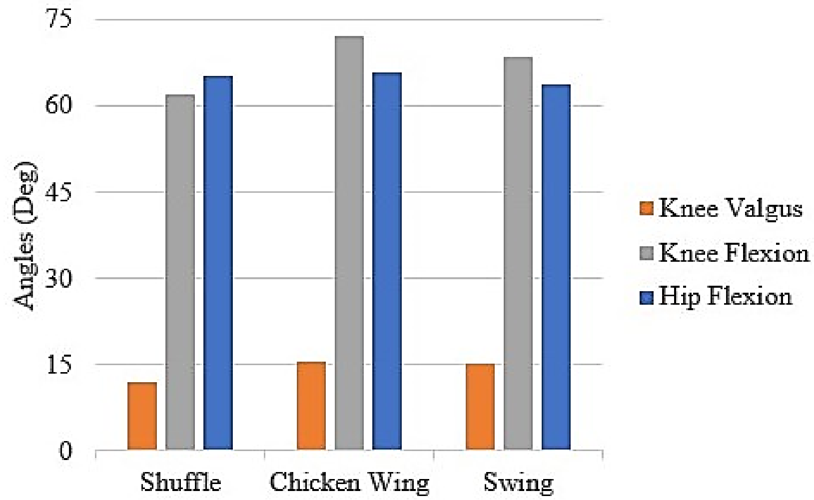


Figure 1. Max angles.

Kinetics variables

Peak Power (W): There was a significant main effect in peak power between the three block jump approaches, ($F_{2,38} = 23.82$, $p < .001$, $\eta^2 = 0.12$). Tukey Test revealed that chicken wing block peak power (4026.50 ± 164.52 W) was significantly higher than shuffle block peak power (3578.76 ± 124.81 W), $p < .001$. Swing block peak power (4148.57 ± 154.93W) was significantly higher than shuffle block peak power, $p < .001$. There was no significant difference between chicken wing and swing block approaches, $p > .05$. See Table 3.

Relative Peak Power (Watt/kg): There was a significant main affect in relative peak power between the three block jump approaches, (F2,38 = 18.89, $p < .001$, $\eta^2 = 0.21$). Chicken wing block relative peak power was significantly higher than shuffle block relative peak power (54.08 ± 1.55 W, and 48.59 ± 1.14 W respectively), $p < .01$. Swing block relative peak power (55.83 ± 1.37 W) was significantly higher than shuffle block relative peak power, $p < .001$. There was no significant difference between chicken wing and swing block approaches, $p > .05$. See Table 3.

Net Impulse (Ns): There was a significant main effect for net impulse between the three block jump approaches, ($F_{2,38} = 9.10$, $p < .001$, $\eta^2 = 0.05$). Chicken wing block net impulse was significantly higher than shuffle block net impulse (174.32 ± 4.67 Ns, and 165.63 ± 5.14 Ns respectively), $p < .05$. Swing block net impulse (175.45 ± 3.94 Ns) was significantly higher than shuffle block net impulse, with $p < .001$. There was no significant difference in net impulse between chicken wing and swing approaches, $p > .05$. See Table 3.

Reactive Strength Index (m/s): There was a significant main effect for reactive strength index between the three block jump approaches, ($F_{2,38} = 9.96$, $p < .001$, $\eta^2 = 0.15$). Chicken wing block reactive strength index was significantly higher than shuffle block reactive strength index (0.6 ± 0.02 m/s, and 0.52 ± 0.02 m/s respectively), $p < .01$. Swing block reactive strength index (0.6 ± 0.02 m/s) was significantly higher than shuffle block reactive strength index, $p < .001$. There was no significant difference in RSI between chicken wing and swing approaches, $p > .05$. See Table 3.

Max Rate of Force Development (N/s): There was a significant main effect for max rate force development between the three block jump approaches, ($F_{2,38} = 12.74$, $p < .001$, $\eta^2 = 0.22$). Tukey Test revealed that chicken wing block max rate of force development (37994.15 ± 2190.95 N/s) was significantly higher than shuffle block max rate of force development (26121.35 ± 1611.65 N/s), with $p < .001$. Swing block max rate of force development (34955.15 ± 2666.52 N/s) was significantly higher than shuffle block max rate of force development, with $p < .01$. There was no significant difference in max rate of force development between chicken wing and swing approaches, $p > .05$. See Table 3.

Peak Force (N): There was a significant main effect of peak force between the three block jump approaches, ($F_{2,38} = 8.62$, $p < .001$, $\eta^2 = 0.13$). Shuffle block peak force (1227.45 ± 40.03 N) was significantly higher than chicken wing block peak force (1082.58 ± 47.31 N), with $p < .05$. Shuffle block peak force was significantly higher than swing block peak force (1073.52 ± 39.02 N), $p < .01$. There was no significant difference in peak force between chicken wing and swing approaches, $p > .05$. See Table 3.

Relative Peak Force (BW): There was a significant main effect for relative peak force between the three block jump approaches, ($F_{2,38} = 7.61$, $p < .002$, $\eta^2 = 0.19$). Shuffle block relative peak force was significantly higher than relative chicken wing block peak force (1.68 ± 0.05, and 1.49 ± 0.05 BW respectively), $p < .05$. Shuffle block relative peak force is significantly higher than relative swing block peak force (1.47 ± 0.04 BW), $p < .01$. There was no significant difference in relative peak force between chicken wing and swing approaches, $p > .05$. See Table 3.

Table 3. Kinetic variables.

	Shuffle Block	Chicken Wing Block	Swing Block
Peak Power (W)	3578.76 ± 124.81	4026.50 ± 164.52	4148.57 ± 154.93
Relative Peak Power (Watt/kg)	48.59 ± 1.14	54.08 ± 1.55	55.83 ± 1.37
Net Impulse (Ns)	165.63 ± 5.14	174.32 ± 4.67	175.45 ± 3.94
Reactive Strength Index (m/s)	0.52 ± 0.02	0.60 ± 0.02	0.60 ± 0.02
Max Rate of Force Development (N/s)	26121.35 ± 1611.65	37994.15 ± 2190.95	34995 ± 2666.52
Peak Force (N)	1227.45 ± 40.03	1082.58 ± 47.31	1073.52 ± 39.02
Relative Peak Force (BW)	1.68 ± 0.05	1.49 ± 0.05	1.47 ± 0.04

Note: mean ± standard deviation.

DISCUSSION

The aims of the study were to investigate differences of kinematics and kinetics variables in three volleyball blocks techniques within the same lateral displacement distance: shuffle block, chicken wing block, and swing block. Our first null hypothesis was that there are no differences in kinematics variables between the three blocks techniques. This null hypothesis was rejected. Overall, chicken wing and swing block produced faster time to take off and higher vertical jump than shuffle block, when covering 1.8 m horizontal distance on a volleyball court.

In terms of effectiveness, the best block approach is the one with the fastest lateral approach, with the highest jump, and greatest hands penetration over the net (Linebach, 2014). The fastest approaches were the chicken wing block (1.61s), and the swing block (1.63s), and both were significantly faster than the shuffle block (1.73s), that utilize lateral steps. The findings of this study were similar to the findings in Buekers (1991), who stated that that the fastest block jump was using a crossover step (i.e., swing and chicken wing block types), while the slowest one was using lateral steps (i.e., shuffle block type). Neves et al. (2011) found that chicken wing block presented significant faster take off time than swing block. Our study did find that time to take off was faster in chicken wing block than in swing block, although not significant. These differences may

 © 2024 ARD Asociación Española

be related to our small sample size (10 participants). On the other hand, Dona et al. (2006) found no significant differences in approach time between shuffle and crossover steps approaches, but those results also can be related to her small sample size based only in three athletes.

In terms of jump height, swing block (28.73 cm) and chicken wing (28.21 cm) were significantly higher than shuffle block (25.43 cm). Although not significant, our study found similar results to Neves et al. (2011) where they found that swing block had a significant higher jump height than the chicken block. These differences may be attributed to the small size of our participant sample. In contrast again, Dona et al. (2006) study did not find significant differences in jump height between shuffle and crossover approaches when analyzing data of only three athletes.

Analyzing the joints angular displacements displayed significant differences in knee flexion angles, while neither knee valgus nor hip flexion displayed significant differences between the three block techniques. Our study found a significant difference in knee flexion angle in the propulsive phase between all three types of block jump techniques. Chicken wing block (72.26 ± 1.34°) had higher knee flexion than swing block (68.64 ± 1.24°) and shuffle block (62.11 ± 1.13°), and swing block was higher than shuffle block, see Figure 1. This difference can be related to the arm movement of the block as was identified by Lees et al. (2004) demonstrating that knee flexion angle changes were related to arms movement (e.g., arm swing vs stationary arm). In addition, the results of our study were different from Lobietti (2009) study, where they found that knee flexion angle at the downward phase was closer to 90 degrees in both shuffle and crossover approaches. This difference can be related to the way the knee angle was measured. In our study we measure the change in angular displacement, whereas they measure angular position.

A review article by Moura and Okazaki (2022) mentioned that the squat depth influences the jump height performance. The best jump performance happens when the knee flexion is smaller than 90 degrees, and when the squat reaches a greater depth, the lower the peak force. In our study, shuffle block was the one that flexed the knees the least before jumping and it achieved the lowest jumps. Chicken swing block was the one that flexed the knees the most before jumping, being the fastest approach, but not the highest jump. While the swing block achieved the highest jumps with an average of 68 degrees of knee flexion. An optimal squat depth may be crucial for jump height performance. The influence of the full arm swing movement to jump in the swing block can unconsciously compensate for the lower knee flexion angles at the time of the jump, compared to the chicken wing which has less influence of the upper limbs in the jump, expanding the role of the lower limbs strength to jump. Even though there was a significant difference between all three block types in terms of max knee flexion, the difference found between chicken wing and swing block did not reflect in a difference in block effectiveness as both achieved similar time to take off and jump height.

Our second null hypothesis was that there are no differences in kinetics variables between the three blocks techniques. This null hypothesis was rejected. Overall, chicken wing and swing block produced higher peak power, net impulse, reactive strength index, max rate of force development than shuffle block, when covering 1.8 m horizontal distance on a volleyball court. Whereas peak force was higher in shuffle block than chicken swing and swing blocks.

The kinetic variables analyzed in this study are good indicators of jump performance, with some more influential than others. Moura and Okazaki (2022), identified that peak power can be the greatest indicator of muscle power during a jump, establishing a positive relationship with jump performance, whereas rate of force development may not predict alone a good jump performance, as it depends on type and velocity of contraction (Moura and Okazaki, 2022). In this present study, chicken wing block and swing block presented the higher values of peak power and max RFD than shuffle block. These findings support the differences in jump height between chicken wing and swing blocks and shuffle block. Impulse is also an essential factor for vertical jump performance. The higher the impulse, the higher is the jump height (Moura and Okazaki, 2022). In our study, both net impulse means of chicken wing and swing blocks were significantly higher than the shuffle one (Table 3), matching with the greatest jump height results. Moura and Okazaki (2022) also mentioned that high peak force is needed but not enough to achieve good jump height performances. In agreement with Moura and Okazaki (2022), our results showed that the type of jump that presented the highest peak force means had the shortest jumps (i.e., shuffle), while the other two types presented higher jumps with significantly lower peak force means, however with higher peak power.

The results of this study are limited to the performance of only ten volleyball players during their off season. However, we believe that the higher level of the athletes can give a better insight to the performance of the three different block techniques. Blocking is also an open skill, in which its efficiency also depends on external factors such as reading and decision-making ability of the athletes, as well as the different types of offensive plays and distances that defensive players must cover. Thus, another limitation that may influence the results is analyzing those three common blocks approaches used in the game, is the fact that the test took place in a laboratory, with a single block displacement covered (1.8 m), and it may constrain the idea of replicating the study in real life scenario.

There are many different movements that athletes are exposed to when learning how to block. When covering a horizontal distance of 1.8 m, it was clear that shuffle block is the weakest option for a good performance. However, it is still unclear what is the best block jump technique option to increase players blocking skill effectiveness, seeing that chicken wing and swing block are similar in many aspects. Thus, coaches may rely on athletes' physical conditions and status (e.g., person height, physiological characteristics, and level of competition) to decide which block approach is better to use in different scenarios.

CONCLUSIONS

When comparing the three most common techniques of a volleyball block jump, the chicken wing and swing block approaches were faster and achieved higher jumps than the shuffle block when covering horizontal distance of 1.8 m. Between chicken wing and swing block types, the only significant difference found was the max knee flexion, which did not impact the overall block jump efficiency. Thus, both chicken wing and swing block jump types are better choices than shuffle block to elevate the block effectiveness of volleyball players, when covering horizontal distance of 1.8 m. Therefore, the study reinforces the need for further investigation on block jump approaches within a game like situation exposure, between different genders, volleyball players role, and volleyball category levels.

AUTHOR CONTRIBUTIONS

Djuly Schmorantz carried out the experiment. Djuly Schmorantz and Tal Amasay contributed to the design of the research, to the analysis of the results and to the writing of the manuscript. All authors provided critical feedback and helped shape the research and manuscript.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

 © 2024 ARD Asociación Española

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Alexander, M., & Honish, A. (2012). Footwork for the volleyball block. Sport Biomechanics Lab University of Manitoba.

Braakhuis, J. G. (2016). Differences in landing impulses between the traditional and swing blocking style in volleyball. Dissertations and Theses @ UNI. 294. Retrieved from [Accessed February 21, 2024]: https://scholarworks.uni.edu/etd/294

Buekers, M.J. (1991) The time structure of the block in volleyball: A comparison of different step techniques. Research Quarterly for Exercise and Sport 62, 232-235. https://doi.org/10.1080/02701367.1991.10608715

Cabarkapa, D., Fry C. A., Cabarkapa, D. X., Rogers, A. C., & Mosier, E. M. (2020). Ground reaction forces of commonly used volleyball blocking approaches. Journal of Kinesiology and Exercise Sciences, 89 (30), 13-20. https://doi.org/10.5604/01.3001.0014.5851

Donà, G., Zorzi, E., Petrone, N., Sawacha, Z., Cobelli, C. (2006). Boimechanical analysis of three different blocking footwork techniques in volleyball: A pilot study. In ISBS-Conference Proceedings Archive. https://doi.org/10.1016/S0021-9290(06)85327-3

Gollhofer, A. & Bruhn, S. (2003). Energy demands in the sport of volleyball. Handbook of sports medicine and science. Volleyball. Eds. Reeser JC, Bahr R. Blackwell Science (pp. 20-28).

Lees, A., Vanrenterghem, J., and Clercq, D. D. (2004). Understanding how an arm swing enhances performance in the vertical jump. Journal of Biomechanics, 37(12), 1929-1940. https://doi.org/10.1016/j.jbiomech.2004.02.021

Linebach, T. L. (2014). A comparative analysis between traditional and swing blocking among division II female volleyball players. Department of Nutrition and Kinesiology University of Central Missouri.

Lobietti, R. (2009). A review of blocking in volleyball: from the notational analysis to biomechanics. Journal of Human Sport & Exercise, 4; 93-99. https://doi.org/10.4100/jhse.2009.42.03

Mosier, E. M., Fry, A. C., & Lane, M. T. (2019). Kinetic contributions of the upper limbs during counter-movement vertical jumps with and without arm swing. The Journal of Strength & Conditioning Research, 33(8), 2066-2073. https://doi.org/10.1519/JSC.0000000000002275

Moura, T. B. M. A., & Okazaki, V. H. A. (2022). Kinematic and kinetic variable determinants on vertical jump performance: a review. MOJ Sports Medicine, (5), 1. https://doi.org/10.15406/mojsm.2022.05.00113

Neves, T.J., Johnson, W.A., Myrer, J.W., & Seeley, M.K. (2011). Comparison of the traditional, swing, and chicken wing volleyball blocking techniques in NCAA division 1 female athletes. Journal of Sports Science and Medicine, 10; 452-457.

Patsiaouras, A., Moustakidis, A., Charitonidis, K., & Kokaridas, D. (2011). Technical Skills Leading in Winning or Losing Volleyball Matches During Beijing Olympic Games. Journal of Physical Education and Sport, 11(2), 149-152. Retrieved from [Accessed February 21, 2024]: https://efsupit.ro/images/stories/7.ASTERIOS_PATSIAOURAS.pdf

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

REVIEW ARTICLE

Approaches on physiological changes in the performance of elite female basketball players: Literature summary

Enkeleida Lleshi . *Sports Research Institute. Department of Sports Performance. Sports University of Tirana. Albania.*
Salvator Kurti. *Department of Sports. Faculty of Movement Science. Sports University of Tirana. Albania.*

ABSTRACT

The international level of elite women's basketball is in great contrast with the Albanian reality regarding the sports performance of the players. The purpose of this literature review is to focus on physiological changes in sports performance during a season in elite female basketball players. Methods: This literature review used a structured methodology to examine the impact of different training loads on the physiological responses of elite female basketball players over 20 years of age during a season. To collect the data for our study, 4 bibliographic databases (PubMed, Scopus, Web of Science and Pro Quest) were used using the Jab Ref program. According to a hybrid of sports scientific methods, we found 60 scientific articles that matched our requirements, integrating anthropometric analysis, body composition, strength tests and speed tests. Conclusions; At the end of this literature review, a more in-depth understanding of the complex effects of training loads on physiological responses and sports performance in female basketball players during competitive sports seasons has been formed. It is for you emphasized the lack of studies on elite women's basketball in Albania in performance evaluation.
Keywords: Female basketball, Elite, Physiological responses, Performance.

Cite this article as:
Lleshi, E., & Kurti, S. (2024). Approaches on physiological changes in the performance of elite female basketball players: Literature summary. *Scientific Journal of Sport and Performance*, *3*(2), 238-250. https://doi.org/10.55860/DJBY5997

Corresponding author. *Sports Research Institute. Department of Sports Performance. Sports University of Tirana. Albania.*
E-mail: elleshi@ust.edu.al
Submitted for publication January 18, 2024.
Accepted for publication February 19, 2024.
Published March 04, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/DJBY5997

INTRODUCTION

Elite women's basketball has experienced a significant increase in global attention, posing a continuous challenge for coaches and training staff to enhance player performance throughout a season. However, there is a stark contrast between the demands of competitive activities in elite European women's basketball competitions and the reality in Albania. Limited studies provide statistics on elite women's basketball teams in the Albanian National Championship, analysing anthropometry, physiological requirements, and the level of performance of elite female basketball players in Albania compared to their international counterparts. Research on basketball indicates that players tend to be taller and heavier, with higher levels of athletic performance. The game has become more strategic due to the development of teams with multiple offensive plays and sophisticated defence strategies (Calleja-González et al., 2015). One particular aspect influencing differences in body height among athletes from different parts of the world is genetics, where certain anthropometric and body composition characteristics of players are linked to specific population characteristics of a particular geographic region. Genetics also influence the anthropometric characteristics of players, which can be associated with athletic performance (Leonardi et al., 2018). Many studies in basketball refer to body composition assessed using sophisticated equipment such as the BodPod. According to authors (Gibson et al., 2009), changes in body composition during a sports season are reported, highlighting the importance of assessing body composition as a key component of physical abilities and high metabolic demands. In basketball, a player's body size largely determines their position on the team (Carling & Orhant, 2010). Berdejo-del-Fresno (2013) analysed body composition among elite British female basketball players and found that they had lower fitness levels and body composition values compared to women's basketball teams from countries where basketball is more popular and developed, possibly due to significant differences in the number of training hours per week.

Basketball is characterized by fast and repetitive movements that require both aerobic and anaerobic energy systems to perform various physical actions such as displacements, jumps, sprints, changes of direction, technical and tactical executions throughout the game, according to authors (Abdelkrim et al., 2010; Metaxas et al., 2009). With the increasing demand for optimal sports performance in basketball, different researchers are constantly trying to discover new ways to gain a competitive advantage, leading to significant advancements in the field of basketball science, as stated by Huyghe et al. (2022). In recent years, exercise physiology research has emphasized the physiological characteristics and differences between females and males, where it has been reported that female basketball players aged between 18 and 32 years have anthropometric and physical parameters linked to sports performance, according to García-Gil et al. (2018). Considerable differences in the analysed variables based on age and gender of athletes have been shown by Mancha-Triguero et al. (2020), mainly due to factors related to natural maturation and anthropometric development at different ages, which influence the efficiency and technical and tactical demands of the performed tests and, consequently, the results obtained from the tests. The authors Vaquera et al. (2015) indicate that the anthropometric characteristics of elite basketball players significantly contribute to their profiling as professional athletes and play a crucial role in the selection process, as these characteristics can have a significant impact on performance. Similarly, García-Gil et al. (2018) demonstrate that certain anthropometric and physical fitness characteristics of female elite basketball players are associated with parameters related to sports performance.

Various studies aim to explore the impact of different training loads on physiological responses and sports performance in elite female basketball players during a season. In the context of basketball, a player's training preparation throughout the different phases of a season has a significant influence on the development of physical abilities, tactics, and emotional resilience of the players (Bali, A. 2015). In this context, analysing training loads is critical to understand how training adapts to the diverse demands of a basketball season, as stated by (Petway et al., 2020). As knowledge advances regarding the periodization of physical loads, it has been observed that periodized training in team sports is of great importance and is a concept that all coaches should be familiar with. The beginning phase of the season is characterized by a relative interruption after the rest and rehabilitation period following the previous season. Studies have shown that careful preparation during this phase can improve fundamental abilities, including basic strength, flexibility, and overall body capacity, according to (Luo et al., 2023). During this time, it is important for coaches to utilize training preparation methods that enhance the foundations of physical abilities, including elements of rehabilitation in case of possible injuries, as indicated by (Bahir et al., 2023). In the mid-season period, when the intensity of the game increases, it is necessary to adapt training programs to address tactical challenges and high game loads. Additionally, it is important to monitor physiological responses during this phase, including heart rate, oxygen consumption, and acidity levels, to ensure continuous adaptation to the game's demands. Authors (Ladwig et al., 2013) have shown changes in body fat percentage before and after a sports season, with an average decrease in BF% of -1.83%, indicating a significant correlation between having a low BF% and game time. As the season approaches its end, where the importance of each match increases, coaches must pay attention to fatigue management and adjust the training program. Carefully managed training loads can influence performance improvement during the peak period of the season, according to (Sansone et al., 2021). Additionally, it is important to consider off-field factors, such as the impact of psychological stress and players' health aspects, as indicated by (Bauman, 2015).

Thus, monitoring each training period provides the coach with relevant information when planning a match, resulting in a positive relationship between improved physical ability and better performance of the athlete in the game, as shown by McGill et al. (2012). To optimize performance in women's basketball, it is necessary to respect the principles of sports training, such as individuality and specificity, as highlighted by Mancha-Triguero et al. (2020). Studies have demonstrated that a carefully tailored program, focused on developing core muscles and motor coordination, has influenced the enhancement of necessary skills for good basketball performance (Luo et al., 2023). Research has observed that incorporating game situations during training, including tactical meetings and improvised scenarios, has aided in the development of tactical awareness and the ability to make quick decisions on the field (Mancha-Triguero et al., 2020; Gabbett et al., 2009; Scalan et al., 2014). In conclusion, this literature review provides a comprehensive understanding of the impact of different training loads on physiological responses and sports performance in elite female basketball players during a season. The results of this analysis offer a solid foundation for the development of personalized training strategies, thereby improving the preparation and performance of players at the highest levels of competition. To achieve this goal, it is important to continue studying and researching in this field, including other aspects.

METHODS

Is used a structured methodology to examine the impact of different training loads on the physiological responses of elite female basketball players during a season. The study integrates various methods from sports science, including anthropometric measurements, body composition analysis, strength tests, and speed tests. The research focuses on monitoring the physiological responses during training and competition at different levels of competition.

The study identified relevant scientific articles using databases such as PubMed, Science Direct, Google Scholar, Scopus, and Web of Science. The selected articles primarily focused on elite female basketball players and explored the aspects of training loads, physiological responses, and performance within the

© 2024 ARD Asociación Española

context of a season. The data from the selected articles were analysed, categorized, and grouped based on common themes and key aspects to facilitate comparisons and synthesis.

The extracted data included anthropometric characteristics, body composition, strength test protocols (such as squat jump, countermovement jump, drop jump 40cm, and explosive force endurance test), and speed tests (such as the 505 Agility Test, Illinois Agility Run Test, and 20m shuttle run VO_2). The structured methodology aims to provide a comprehensive and accurate analysis of the impact of training loads on the physiological responses of elite female basketball players during a season. This hybrid approach will enable a precise assessment of player performance, assist in the development of personalized training protocols, and enhance their performance at the elite level. Through the literature review, it has been evident that previous studies and analyses have provided a clear understanding of the impact of training loads on the physiological responses of elite female basketball players. The following section will present some of the key findings obtained through the analysis of the selected literature.

RESULTS

From this selection process of scientific articles that we identified through database searches (keywords) and that were reviewed based on titles, abstracts and full studies, we focused on considering only 60 studies for the full evaluation of eligibility according to our criteria. Table 1 presents the details of all the processes and results obtained from the search strategy for this literature review for each of the categories analysed and that were adapted to the data on the physiological changes of sports performance during the sports season in elite female basketball.

Table 1. Results of literature review.

Analysed Category Estimated Parameters	**Author, Year of Publication Title of the article**	**Key Findings**
Anthropometry Body Height (cm) Body Weight (kg) Body Composition (%)	***(Miguel-Ortega et al., 2023)*** "Comparison of sports performance and anthropometric profiles of elite female basketball and volleyball players during a competition".	Lean body mass is an important predictor of exercise performance intensity. Excess fat mass is detrimental to the development of strength and endurance.
	(Bravo et al., 2021) "Anthropometric analysis of an elite women's basketball team during the first half of a regular season".	The results show a favourable anthropometric evolution, in contrast to the fact that the main anthropometric changes occur during the regular season.
	(Drinkwater et al., 2008). "Design and interpretation of anthropometric and fitness tests of basketball players".	A battery of specific physical tests can be used to assess body composition, aerobic capacity & strength, practical methods of interpreting changes between players have been identified, to assess the effectiveness of training programs
Force, Speed, Vertical Jump Squat Jump (SJ) (cm) Countermovement Jump (CMJ) (cm) (DJ40cm) (cm) T drill agility test Drop Jump 40cm	***(Alemdaroğlu, 2012).*** "The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players".	Positive correlation between explosive strength and speed on the field. Players with a higher CMJ tend to have high court speeds. Performance in explosive strength tests is related to speed and manoeuvrability. Players with a higher CMJ tend to have high court speeds.
	(Lleshi, 2019). "Plyometric assessment of women's basketball-volleyball performance".	Through the Drop Jump test, it is possible to evaluate high and low performances not only from the height of the vertical jump development but also from the phase of staying in the air

Speed, Agility, Jump 505 Agility Test (s)	***(Horníková & Zemková, 2021).*** "The relationship between physical factors and variation in running speed in team sports".	It showed the relationship between CODS and linear sprint speed, jumping ability and muscle strength. CODS correlated significantly with sprint time for 10 m, 20 m, and 30 m, but not with time for the shortest sprint (5 m).
	(Sugiyama et al., 2021). Change of Direction Speed Tests in Basketball Players: A Brief Review of Test Varieties and Recent Trends".	The results suggest that while CODS performance in basketball players is studied with different tests, recent studies give equal weight to the three types of tests characterized by cutting-type incremental adaptation to assess CODS-specific performance.
Illinois Agility Run Test (sec)	***(Vescovi & McGuigan, 2008).*** "Relationships between sprinting, agility and jumping ability in female athletes".	The results suggest that sprinting, agility and jumping ability are common physiological and biomechanical determinants. The findings of the study show a significant relationship between jumping ability and agility performance and sprint time in young basketball players
20 m Shuttle Run VO_2 (s)	***(Stanković et al., 2023).*** "Effects of high-intensity interval training (HIIT) on physical performance in women's team sports: A systematic review.	HIIT has significant effects on VO_{2max}, RSA, and change in running speed, speed and explosive strength in women's team sports regardless of competition level.
Physiological Adaptation Heart Rate in jump (bpm)	***(Batalla-Gavalda et al., 2023).*** "A new database of the analysis of physiological needs in amateur women's basketball during official matches".	High heart rate levels have been associated with better fitness in intense dance training sessions.
	(McInnes et al., 1995). "Physiological load placed on basketball players during the competition".	In this study, it was concluded that through the analysis of heart rate data, coaches can identify the intensity and duration of physical activity during games, enabling the development of more effective training programs.
Oxygen Consumption (VO_{2max})	***(McInnes et al., 1995).*** "Physiological load placed on basketball players during the competition".	Basketball players with a high VO_{2max} tend to have an improved capacity to sustain the high intensity of the game. The study concludes that the physiological demands of soccer players are high, placing significant demands on the players' cardiovascular and metabolic capacities.
The yield of Metabolism Anaerobic Lactic Acidity (mmol/L)	***(Norkowski, 2002).*** "Anaerobic power of handball players representing different sports levels".	High levels of lactic acid are associated with actions and the ability to perform intense efforts.
Motor Ability Vertical Jump (cm)	***(Shalfawi et al., 2011).*** "The relationship between running speed and vertical jump measure in professional basketball players: a field test approach".	The results of this study show that while there is a strong and pronounced relationship between the 10-, 20-, and 40-m sprints, there is also considerable variation in the factors that contribute to performance at these distances. This may indicate that specific training strategies can be implemented to improve running speed over these distances.
Motor Coordination	***(Chaouachi et al., 2009).*** "Maximum dynamic strength and determinants of lower limb agility in elite basketball players".	A significant negative correlation was observed between the performance of the t-test and the 5-jump test ($r = -0.61$, $p = .02$). Squat 1RM was significantly related to 5-, 10-, and 30-m sprint times.
	(Šalaj & Marković, 2011). "Specification of the motor skills of jumping, sprinting and changing the speed of running".	Stepwise correlation analysis showed that body fat percentage was the single best predictor ($p < 0.05$) of agility. Squat 1RM performance was the single best predictor of 5-m and 10-m sprint times ($p < 0.05$). In light of the findings of the current study, flexibility should be considered a physiological ability in itself for elite basketball players.

© 2024 ARD Asociación Española

Stability and Body Strength Plank Fitness Test	***(Cronin & Hansen, 2005).*** "Predictors of Strength and Power in Sports Speed".	It was suggested that improving power-to-weight ratio as well as plyometric training involving countermovement and loaded jump-squat training may be more effective for increasing athletic speed in elite players.
	(Bissas & Havenetidis, 2008). "The use of different power tests as predictors of sprint running performance".	The present findings suggest that the ability to produce force quickly, as measured by the time to reach 60% of maximal voluntary contraction, is related to running performance, with the coefficient of determination accounting for 53% of the variance. These data also show that sprinting ability is related to DJ performance, particularly in the 30 cm drop jump. It is suggested that the above tests may be useful in preparing and testing sprint ability.
Leg Muscle Strength	***(Young et al., 2011).*** "What jumping variables should be used to assess explosive leg muscle function?"	The results show that if an integrated system including a position transducer and a force platform is available for CMJ assessment, jump height and peak power/weight are useful variables to describe explosive leg muscle function for athletes performing sprint.

DISCUSSIONS

The discussion of the data in this literature review can focus on several main themes that arise from the results of the included studies. This discussion will be based on anthropometric data, strength, speed, physiological adaptation, and body stability and strength. Based on these key points, the data from the articles included in this literature review are presented as follows:

Anthropometry and evolution throughout the season

According to the study by Miguel-Ortega et al. (2023), positive results were shown in anthropometric evolution during the season, focusing on female basketball and volleyball players, resulting in changes in body composition throughout the season. Similarly, the study by Bravo et al. (2021) focused on the initial analysis of a specific period of the sports season, where there may be variations in anthropometric characteristics compared to the previous study by Miguel-Ortega et al. (2023). The study by Drinkwater et al. (2008) focuses on the design and interpretation of anthropometric and physical fitness tests in basketball players and provides recommendations for the use of anthropometric tests in the training of basketball players.

Explosive strength and speed

The study by Alemdaroğlu (2012) demonstrates a positive relationship between explosive strength and speed on the field, where the Countermovement Jump (CMJ) test is used as one of the key indicators for explosive strength, and it is found that players with higher CMJ tend to have higher speed. The study by Lleshi (2019) also reported that tests of explosive strength are used to assess the performance of female basketball and volleyball players, which is related to speed and jumping ability.

Speed and jumping ability

According to the study by Horníková & Zemková (2021), there is a relationship between the 505 Agility test and linear sprint speed, which aims to determine the relationship between physical factors and speed in basketball. Similarly, the study by Sugiyama et al. (2021) shows the connection between change of direction speed (CODS) and sprint speed, including an analysis of trends and the use of various tests to assess

CODS performance. According to Pojskić et al. (2015), their study concluded that strength and aerobic and anaerobic capacities can be good differentiating variables among players with different roles based on positions.

Physiological adaptation

Analysis of heart rate during official female basketball games according to the authors (Batalla-Gavalda et al., 2023) has led to the identification of high levels of heart rate and fitness during intense dance sessions. The possibility of identifying the intensity and duration of physical activity during games has also been reflected by the authors (McINNES et al., 1995) in the analysis of the physiological demands of basketball during competitions as well as the yield of anaerobic metabolism, and they determine that the metabolic demands are high in basketball. The study of (Norkowski, 2002) argues that aerobic and technical potential as well as tactical ability are also important for the quality of a team where motor adaptability and motor coordination are also needed. Strong correlation between sprint speed and jump height has been shown in the authors' study (Shalfawi et al., 2011) in the use of jump and speed tests in the preparation and testing of sports speed. But according to the authors (Chaouachi et al., 2009) a negative correlation is shown between the performance in the Plank test and the ability to perform sprint times, which includes the analysis of factors that contribute to jumping and sprinting performance. According to the authors (Plasa & Koci, 2023) in a study with the National women's team in Albania, it was concluded that the RAST test (Running Anaerobic Sprint Test) is an excellent indicator of measuring hyper lactate and through it anaerobic performance is evidenced. The most common demand analysis in basketball has been internal load analysis through heart rate and subjective scales and external load analysis by time motion analysis according to the authors (Reina et al., 2020). Physiologically, the body's responses to training loads vary across the phases of the season. Studies have identified changes in heart rate, oxygen consumption and muscle acidity during intense exercise (Montgomery et al., 2010). Off-court factors, including nutrition, environmental influence and psychological stress, are also essential for the preparation and performance of female elite basketball players according to (Stojanović et al., 2017). (Cronin & Hansen, 2005)'s study focuses on strength and speed predictors and proposes that improving power-to-weight ratio and plyometric training may be more effective. The authors (Bissas & Havenetidis, 2008) in their study propose that performance in the 5-jump test is the best predictor of 5-m and 10-m sprint times.

Training loads

The control and monitoring of the training load requires scientific information for the creation of different protocols to evaluate sports performances. Testing and monitoring the skills and performance of players can have multiple purposes, but we need to evaluate the effectiveness of training programs or monitor actual levels of sports performance. In our framework, knowledge gaps have appeared in the analysis of training load, body composition and fitness level in elite women's basketball in Albania, so a proper assessment and periodization of training loads are essential in the development of sports performance. Analysis of internal and external load by means of a test of anaerobic and aerobic capacities is not a common practice for players in the training phases. Recently, there has been an increase in interest in the management and monitoring of internal and external loads to reduce the risk of injury and improve sports performance according to (Weiss et al., 2017). There are two types of loads: (1) external load, or the amount of work done in a period of time or period of activity, and (2) internal load, or the psycho-physiological response to the external load. Rating of perceived exertion (RPE) has emerged as a widely used method for monitoring workload in several team sports according to (Bourdon et al., 2017) including basketball (Russell et al., 2020). On the other hand, the internal load depends on the internal psycho-physiological factors of the athlete, such as motivation, stress, fatigue, cognitive capacity, age, gender, sports experience and physical condition. Monitoring internal loading in basketball can be used to understand the effects and possible

 © 2024 ARD Asociación Española

physiological adaptations caused by external loading. McLaren et al. (2017) report that measures of internal load derived from perceived exertion and heart rate show consistent positive associations with external loads and intensity derived from running and accelerometer during training and competition in team sports, but the magnitude and uncertainty of these relationships depend on the amount and method of training. Monitoring training loads in basketball is particularly important within team members as different individuals respond in different ways to training sessions, which involves quantifying external and internal load. External load monitoring presents one of the most unique challenges due to the cost and accessibility of methods commonly used in other team sports according to a review by (Fox et al., 2017). Many tests are used for selection methods and procedures, to screen candidates, or to monitor the effectiveness of training programs by (Norkowski, 2002). According to (Legg et al., 2017) that aimed to quantify changes in jump performance and variability in elite female basketball players, it shows that in-season loads not only impair jump performance, but also movement variability in basketball players. De Freitas Cruz et al. (2018) showed that the results of the study highlight the importance of using a comprehensive and multivariate approach to effectively monitor the physical performance of young athletes. The RAST was also used to assess anaerobic fitness exclusively in professional players, prohibiting the ability to compare performance between levels of competition. Insufficient studies were noted to draw conclusions regarding positional changes in RAST performance in basketball players. According to the authors (Plasa & Koci, 2023) in a study with the National women's team in Albania, it was concluded that the RAST test (Running Anaerobic Sprint Test) is an excellent indicator of measuring hyper lactate and through it anaerobic performance is evidenced. Monitoring fitness at each training session provides the coach with relevant information when planning a competition, with a positive relationship then existing between better fitness and better athlete performance in competition (McGill et al., 2012). . It is important to identify what are the obstacles encountered in cargo monitoring so that practical solutions can be found to alleviate the needs of practitioners according to (Fox et al., 2019). Assessment of players' physical fitness during an entire basketball season allows monitoring the effectiveness of conditioning programs and quantifying changes in player fitness status at different stages of the season (Drinkwater et al., 2008). The greatest improvement in the physical fitness of athletes usually occurs during the preparation period, when players begin to perform a physical activity after a relatively long period of complete or almost complete rest (Hoffman, 2000). Despite the fact that the preparatory period represents a crucial phase for optimizing the performance of athletes, information about the appropriate level of load and training, in the volume and intensity that they are carried out during this period, the relationships between the training load and changes in the fitness levels of players is limited, they have not yet been researched in elite women's basketball in Albania.

CONCLUSIONS

This literature review provides a rich perspective on the factors that influence the sports performance of elite female basketball players. However, it is important to note that discontinuities and variations between studies may be the result of a variety of factors, including initial skill levels, training methods, and seasonal conditions. All of the aforementioned findings play an important role in the ongoing research of elite women's basketball. This review collects a good portion of the tests and outcome variables used to assess the physical characteristics of basketball players in the literature to date. The number of tests and outcome variables identified confirm that a test battery is needed for the assessment of physical characteristics of basketball players. Training that focuses on body strength and stability can be important for improving their performance. The development of test batteries at the level of elite female basketball in Albania would enable the longitudinal evaluation of players and the establishment of minimum physical standards for playing positions and levels of competition. Evaluation methods often change in relation to the new technologies used. Given the limited amount of research in elite women's basketball that assesses physical parameters of sport performance: further research is needed to explore potential differences between players across playing positions and levels of competition to develop efficient testing and training-based scientific research. In conclusion, load management in basketball requires a scientific approach to evaluate and analyse the internal and external load of players for the development of analytical evaluation protocols. For more, there is a need for updated research that includes studies on female players, given the growing interest in women's basketball.

AUTHOR CONTRIBUTIONS

The contribution to this review is joint, where Salvator Kurti is a PhD candidate and Enkeleida Lleshi is her scientific leader.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Abdelkrim, N. B., Castagna, C., Jabri, I., Battikh, T., Fazâa, S. E., & Ati, J. E. (2010). Activity profile and physiological requirements of junior Elite basketball players in relation to Aerobic-Anaerobic Fitness. The Journal of Strength and Conditioning Research, 24(9), 2330-2342. https://doi.org/10.1519/JSC.0b013e3181e381c1

Alemdaroğlu, U. (2012). The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. Journal of Human Kinetics, 31(2012), 149-158. https://doi.org/10.2478/v10078-012-0016-6

Bahir, H., Xiaoyun, W., & Z Habibi, M. (2023). Key Skills of Physical Training in Track and Field Teaching and Training in Higher Vocational Faculty. Austin Sports Medicine, 8(1), 1054. https://doi.org/10.33582/JFamMedCare.2023.1001

Bali, A. (2015). Psychological factors affecting sports performance. Journal of Physical Education, Sports and Health, 1(6), 92-95.

Batalla-Gavalda, A., Montoliu, R., Beltrán-Garrido, J. V., & Corbi, F. (2023). A new database of the analysis of the physiological needs in amateur female basketball during official matches. Scientific Data, 10(1). https://doi.org/10.1038/s41597-023-02747-2

Bauman, N. J. (2015). The stigma of mental health in athletes: are mental toughness and mental health seen as contradictory in elite sport? British Journal of Sports Medicine, 50(3), 135-136. https://doi.org/10.1136/bjsports-2015-095570

Berdejo-del-Fresno, D. (2013). Female British Basketball: research studies into body composition, fitness level and training load. Asociación Didáctica Andalucía (Spain).

Bissas, & Havenetidis. (2008). The use of various strength-power tests as predictors of sprint running performance. PubMed, 48(1), 49-54.

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P. B., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., & Cable, N. T. (2017). Monitoring Athlete Training Loads: Consensus

 © 2024 ARD Asociación Española

Statement. International Journal of Sports Physiology and Performance, 12(s2), S2-170. https://doi.org/10.1123/IJSPP.2017-0208
Bravo, I. R., García, J. D., López-Gajardo, M. Á., & Ponce-Bordón, J. C. (2021). Análisis antropométrico de un equipo de baloncesto femenino de élite durante la primera parte de una temporada regular. E-motion, 16, 24-34. https://doi.org/10.33776/remo.v0i16.5121
Calleja-González, J., Cepeda, N. T., Mielgo-Ayuso, J., Delextrat, A., Jukić, I., Vaquera, A., Torres, L., Schelling, X., Stojanović, M., & Ostojić, S. M. (2015). Evidence-based post-exercise recovery strategies in basketball. The Physician and Sportsmedicine, 44(1), 74-78. https://doi.org/10.1080/00913847.2016.1102033
Carling, C., & Orhant, E. (2010). Variation in body composition in professional soccer players: interseasonal and intraseasonal changes and the effects of exposure time and player position. The Journal of Strength and Conditioning Research, 24(5), 1332-1339. https://doi.org/10.1519/JSC.0b013e3181cc6154
Chaouachi, A., Brughelli, M., Chamari, K., Levin, G. T., Abdelkrim, N. B., Laurencelle, L., & Castagna, C. (2009). Lower limb maximal dynamic strength and agility determinants in elite basketball players. The Journal of Strength and Conditioning Research, 23(5), 1570-1577. https://doi.org/10.1519/JSC.0b013e3181a4e7f0
Cronin, J., & Hansen, K. T. (2005). Strength and power predictors of sports speed. The Journal of Strength and Conditioning Research, 19(2), 349. https://doi.org/10.1519/14323.1
De Freitas Cruz, I., Pereira, L. A., Kobal, R., Kitamura, K., Cedra, C., Loturco, I., & Abad, C. C. C. (2018). Perceived training load and jumping responses following nine weeks of a competitive period in young female basketball players. PeerJ, 6, e5225. https://doi.org/10.7717/peerj.5225
Delextrat, A., & Cohen, D. D. (2009). Strength, power, speed, and agility of women basketball players according to playing position. The Journal of Strength and Conditioning Research, 23(7), 1974-1981. https://doi.org/10.1519/JSC.0b013e3181b86a7e
Drinkwater, E. J., Pyne, D. B., & McKenna, M. J. (2008). Design and interpretation of anthropometric and fitness testing of basketball players. Sports Medicine, 38(7), 565-578. https://doi.org/10.2165/00007256-200838070-00004
Elliott-Sale, K. J., Minahan, C., De Jonge, X. J., Ackerman, K. E., Sipilä, S., Constantini, N., Lebrun, C. M., & Hackney, A. C. (2021). Methodological Considerations for Studies in Sport and Exercise Science with Women as Participants: A Working Guide for Standards of Practice for Research on Women. Sports Medicine, 51(5), 843-861. https://doi.org/10.1007/s40279-021-01435-8
Espasa-Labrador, J., Fort-Vanmeerhaeghe, A., Montalvo, A. M., Carrasco-Marginet, M., Irurtia, A., & Calleja-González, J. (2023). Monitoring Internal Load in Women's Basketball via Subjective and Device-Based Methods: A Systematic review. Sensors, 23(9), 4447. https://doi.org/10.3390/s23094447
Fox, J. L., Scanlan, A. T., Sargent, C., & Stanton, R. (2019). A survey of player monitoring approaches and microsensor use in basketball. Journal of Human Sport and Exercise, 15(1). https://doi.org/10.14198/jhse.2020.151.20
Fox, J. L., Scanlan, A. T., & Stanton, R. (2017). A review of player monitoring approaches in Basketball: Current trends and future directions. The Journal of Strength and Conditioning Research, 31(7), 2021-2029. https://doi.org/10.1519/JSC.0000000000001964
Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2009). Game-Based training for improving skill and physical fitness in team sport athletes. International Journal of Sports Science & Coaching, 4(2), 273-283. https://doi.org/10.1260/174795409788549553
García-Gil, M., Torres-Unda, J., Esain, I., Duñabeitia, I., Gil, S. M., Gil, J., & Irazusta, J. (2018). Anthropometric parameters, age, and agility as performance predictors in elite female basketball players. The Journal of Strength and Conditioning Research, 32(6), 1723-1730. https://doi.org/10.1519/JSC.0000000000002043

Gibson, D. G., Young, L. S., Chuang, R. Y., Venter, J. C., Hutchison, C. A., & Smith, H. O. (2009). Enzymatic assembly of DNA molecules up to several hundred kilobases. Nature Methods, 6(5), 343-345. https://doi.org/10.1038/nmeth.1318

Gutiérrez-Vargas, R., Ugalde-Ramírez, A., Pino-Ortega, J., Trejos-Montoya, J., Blanco-Romero, L., Sánchez-Ureña, B., Gutiérrez-Vargas, J. C., & Rojas-Valverde, D. (2022). Anthropometric, aerobic and muscle power profile of young Costa Rican basketball players. Pensar En Movimiento: Revista De Ciencias Del Ejercicio Y La Salud, 20(2), e48357. https://doi.org/10.15517/pensarmov.v20i2.48357

Helwig, J., Diels, J., Röll, M., Mahler, H., Gollhofer, A., Röecker, K., & Willwacher, S. (2023). Relationships between External, Wearable Sensor-Based, and Internal Parameters: A Systematic Review. Sensors, 23(2), 827. https://doi.org/10.3390/s23020827

Hoffman, M. L. (2000). Empathy and moral development. https://doi.org/10.1017/CBO9780511805851

Horníková, H., & Zemková, E. (2021). Relationship between Physical Factors and Change of Direction Speed in Team Sports. Applied Sciences, 11(2), 655. https://doi.org/10.3390/app11020655

Huyghe, T., Alcaraz, P. E., Calleja-González, J., & Bird, S. P. (2021). The underpinning factors of NBA game-play performance: a systematic review (2001-2020). The Physician and Sportsmedicine, 50(2), 94-122. https://doi.org/10.1080/00913847.2021.1896957

Kong, Z., Fu, Q., & Shi, Q. (2015). The influence of basketball dribbling on repeated high-intensity intermittent runs. Journal of Exercise Science & Fitness, 13(2), 117-122. https://doi.org/10.1016/j.jesf.2015.10.001

Ladwig, E., Ladwig, E. B., Justin, Shim, L., Yom, P., Cross, P., & Beebe, J. (2013). Preseason And Post Season Body Composition Does Not Change Relative To Playing Time In Division I Female Basketball Players. International Journal of Exercise Science 6(3) : 208-216, 2013., 6(3), 208-2016. Retrieved from [Accessed February 24 2024]: https://digitalcommons.wku.edu/ijes/vol6/iss3/4

Legg, J. S., Pyne, D. B., Semple, S., & Ball, N. (2017). Variability of jump kinetics related to training load in elite female basketball. Sports, 5(4), 85. https://doi.org/10.3390/sports5040085

Leonardi, T. J., Paes, R. R., Breder, L., Foster, C., Gonçalves, C. E., & Carvalho, H. M. (2018). Biological maturation, training experience, body size and functional capacity of adolescent female basketball players: A Bayesian analysis. International Journal of Sports Science & Coaching, 13(5), 713-722. https://doi.org/10.1177/1747954118772489

Lleshi, E. (2019). Plyometric Performance Assessment of Basketball - Volleyball female players. European Journal of Interdisciplinary Studies, 5(2), 54. https://doi.org/10.26417/200kaz71n

Luo, S., Soh, K. G., Zhao, Y., Soh, K. L., Sun, H., Nasiruddin, N. J. M., Zhai, X., & Ma, L. (2023). Effect of core training on athletic and skill performance of basketball players: A systematic review. PLOS ONE, 18(6), e0287379. https://doi.org/10.1371/journal.pone.0287379

Mancha-Triguero, D., García-Rubio, J., Medina, A. A., & Godoy, S. J. I. (2020). Physical and physiological profiles of aerobic and anaerobic capacities in young basketball players. International Journal of Environmental Research and Public Health, 17(4), 1409. https://doi.org/10.3390/ijerph17041409

McGill, S. M., Andersen, J., & Horne, A. D. (2012). Predicting performance and injury resilience from movement quality and fitness scores in a basketball team over 2 years. The Journal of Strength and Conditioning Research, 26(7), 1731-1739. https://doi.org/10.1519/JSC.0b013e3182576a76

McInnes, S. J., Carlson, J., Jones, C. J., & McKenna, M. J. (1995). The physiological load imposed on basketball players during competition. Journal of Sports Sciences, 13(5), 387-397. https://doi.org/10.1080/02640419508732254

McLaren, S. J., Macpherson, T., Coutts, A. J., Hurst, C., Spears, I. R., & Weston, M. (2017). The Relationships between internal and external measures of training load and intensity in Team Sports: A Meta-Analysis. Sports Medicine, 48(3), 641-658. https://doi.org/10.1007/s40279-017-0830-z

 © 2024 ARD Asociación Española

Metaxas, T., Koutlianos, N., Sendelides, T., & Mandroukas, A. (2009). Preseason Physiological profile of soccer and basketball players in different divisions. The Journal of Strength and Conditioning Research, 23(6), 1704-1713. https://doi.org/10.1519/JSC.0b013e3181b3e0c5

Miguel-Ortega, Á., Calleja-González, J., & Mielgo-Ayuso, J. (2023). Comparison of Sports Performance and Kinanthropometric Profiles of Elite Female Basketball and Volleyball Players over the Course of a Competitive Season. Applied Sciences, 13(14), 8267. https://doi.org/10.3390/app13148267

Montgomery, P. G., Pyne, D. B., & Minahan, C. (2010). The physical and physiological demands of basketball training and competition. International Journal of Sports Physiology and Performance, 5(1), 75-86. https://doi.org/10.1123/ijspp.5.1.75

Norkowski. (2002). Anaerobic power of handball players representing various sport levels. Journal of Human Kinetiks, 7(1), 43-50.

Petway, A., Freitas, T. T., Calleja-González, J., Leal, D. M., & Alcaráz, P. E. (2020). Training load and match-play demands in basketball based on competition level: A systematic review. PLOS ONE, 15(3), e0229212. https://doi.org/10.1371/journal.pone.0229212

Plasa, M., & Koci, L. (2023). Assessment Running Anaerobic Sprint Test (RAST) in female basketball players. Journal of Physical Activity and Sports, 5(1), 83-91. Retrieved from [Accessed February 24 2024]: https://ust.edu.al/wp-content/uploads/2023/06/JPAS-2023.pdf

Pojskić, H., Šeparović, V., Užičanin, E., Muratović, M., & Mačković, S. (2015). Positional role Differences in the aerobic and anaerobic power of elite basketball players. Journal of Human Kinetics, 49(1), 219-227. https://doi.org/10.1515/hukin-2015-0124

Reina, M., García-Rubio, J., & Godoy, S. J. I. (2020). Training and competition load in Female Basketball: A Systematic review. International Journal of Environmental Research and Public Health, 17(8), 2639. https://doi.org/10.3390/ijerph17082639

Russell, J., McLean, B. D., Impellizzeri, F. M., Strack, D. S., & Coutts, A. J. (2020). Measuring Physical Demands in Basketball: An Explorative Systematic Review of Practices. Sports Medicine, 51(1), 81-112. https://doi.org/10.1007/s40279-020-01375-9

Šalaj, S., & Marković, G. (2011). Specificity of jumping, sprinting, and quick Change-of-Direction motor abilities. The Journal of Strength and Conditioning Research, 25(5), 1249-1255. https://doi.org/10.1519/JSC.0b013e3181da77df

Sansone, P., Gasperi, L., Tessitore, A., & Gómez, M. Á. (2021). Training load, recovery and game performance in semiprofessional male basketball: influence of individual characteristics and contextual factors. Biology of Sport, 38(2), 207-217. https://doi.org/10.5114/biolsport.2020.98451

Scanlan, A. T., Dascombe, B. J., & Reaburn, P. (2011). A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. Journal of Sports Sciences, 29(11), 1153-1160. https://doi.org/10.1080/02640414.2011.582509

Scanlan, A. T., Wen, N., Tucker, P., & Dalbo, V. J. (2014). The relationships between internal and external training load models during basketball training. The Journal of Strength and Conditioning Research, 28(9), 2397-2405. https://doi.org/10.1519/JSC.0000000000000458

Shalfawi, S. a. I., Sabbah, A., Kailani, G., Tønnessen, E., & Enoksen, E. (2011). The relationship between running speed and measures of vertical jump in Professional Basketball Players: A Field-Test Approach. The Journal of Strength and Conditioning Research, 25(11), 3088-3092. https://doi.org/10.1519/JSC.0b013e318212db0e

Stanković, M., Djordjevic, D., Trajković, N., & Milanović, Z. (2023). Effects of High-Intensity Interval Training (HIIT) on Physical Performance in female team Sports: a systematic review. Sports Medicine - Open, 9(1). https://doi.org/10.1186/s40798-023-00623-2

Stojanović, E., Stojiljković, N., Scanlan, A. T., Dalbo, V. J., Berkelmans, D. M., & Milanović, Z. (2017). The activity demands and Physiological Responses Encountered During Basketball Match-Play: A Systematic review. Sports Medicine, 48(1), 111-135. https://doi.org/10.1007/s40279-017-0794-z

Sugiyama, T., Maeo, S., Kurihara, T., Kanehisa, H., & Isaka, T. (2021). Change of direction Speed tests in basketball players: A brief review of test varieties and recent trends. Frontiers in Sports and Active Living, 3. https://doi.org/10.3389/fspor.2021.645350

Vaquera, A., Santiago, S., Gerardo, V. J., Carlos, M. J., & García-Tormo, V. (2015). Anthropometric characteristics of Spanish professional basketball players. Journal of Human Kinetics, 46(1), 99-106. https://doi.org/10.1515/hukin-2015-0038

Vescovi, J. D., & McGuigan, M. R. (2008). Relationships between sprinting, agility, and jump ability in female athletes. Journal of Sports Sciences, 26(1), 97-107. https://doi.org/10.1080/02640410701348644

Weiss, K. J., Allen, S. V., McGuigan, M. R., & Whatman, C. (2017). The relationship between training load and injury in men's professional basketball. International Journal of Sports Physiology and Performance, 12(9), 1238-1242. https://doi.org/10.1123/ijspp.2016-0726

Young, W., Cormack, S. J., & Crichton, M. (2011). Which jump variables should be used to assess explosive leg muscle function? International Journal of Sports Physiology and Performance, 6(1), 51-57. https://doi.org/10.1123/ijspp.6.1.51

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Physical activity participation of university students in the United Kingdom

Oscar Rhodes . *Department of Physical and Sport Education. University of Valencia. Valencia, Spain.*

ABSTRACT

Every year more than 2.38 million students attend university in the United Kingdom. However, there is limited research up to this date addressing current physical activity participation of the university students in the United Kingdom. This study explored the current physical activity habits among students studying at university level in the United Kingdom. An online survey was administered and completed by 466 students from over 52 faculties. Participants answered questions on demographic variables such as gender, age, socioeconomic status of family, location of studies, types of studies, year of studies, living arrangements and monthly expenditure. They were provided the English version of the IPAQ-Short form and asked to fill out the questionnaire with their physical activity habits during a typical week of university study. Results identified 64.4% of the sample were "*moderate*" active, with 14.2% "*high*" and 18.5% "*low*" active as categorized by the IPAQ-Short form scoring. Disparities in physical activity participation were present on demographic variables such as gender, year of study and family socioeconomic level upon analysis by ANOVA. To conclude, a discussion of the results within the overall field of physical activity participation in higher education was positioned and critiqued.

Keywords: Performance education, Physical activity, Participation, Students, United Kingdom, University.

Cite this article as:
Rhodes, O. (2024). Physical activity participation of university students in the United Kingdom. *Scientific Journal of Sport and Performance*, *3*(2), 251-260. https://doi.org/10.55860/LUIG7901

Corresponding author. *Department of Physical and Sport Education. University of Valencia. Valencia, Spain.*
E-mail: 98oscar@hotmail.es
Submitted for publication January 30, 2024.
Accepted for publication February 19, 2024.
Published March 04, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/LUIG7901

INTRODUCTION

Frequent physical activity remains a vital behaviour for promoting health, delaying, or preventing prevalent musculoskeletal disorders such as mechanical low back pain, neck and shoulder pain and decreasing the risk of developing hypertension, diabetes, osteoporosis, obesity, colon cancer and coronary heart disease (Jones et al, 1998; Vuori, 1995). Many studies outline the worldwide decline of physical activity, and the increase of obesity and other disease risks (WHO, 2010). Physical activity may reduce those risks while constructing and maintaining healthy muscle and bone, reduce obesity, reduce stress and anxiety, and promote well-being and healthy lifestyle to its participants (El-Gilany et al 2011).

It has been suggested in the physical activity literature that interventions aimed at increasing physical activity participation should be tailored to specific population subgroups such as women, middle-aged and older adults, and rural residents (King et al,2000; Blanchard et al, 2005; Gangeness, 2010).

The period of adolescence represents the transition from childhood to adulthood and the formation of lifetime habits such as regular exercise are normally formulated during this transition (Andersen & Haraldsdottir, 1993; Engstrom, 1986). Research suggests that physical activity rates decline consistently throughout this stage. Many factors may affect participation levels. These include demographic variables, knowledge, attitudes, and beliefs about physical activity, as well as other sociocultural issues. The steepest decline was evident during the stage of entering university (Kwan et a, 2012; Sigmundova et al, 2013; Fagaras et al, 2015). Over one third of active students in high school became insufficiently active upon transitioning to university life.

In the literature, demographics (e.g., age, gender), psychological factors (e.g., self- efficacy, perceived enjoyment), social factors (social support from family and friends), and physical environmental factors (e.g., living/built environment, access to facilities) were reported to be feasibly influencing factors of college/university students' physical activity participation (Haase et al, 2004; Reed & Phillips, 2005). Haase (2004) believes the relationship between physical activity participation is affected by several individual factors such as culture, cost, environment, gender and living arrangement within the university population. Current university cohort research within the UK has been inconclusive. Adults should engage in 150 minutes of moderate-intensity physical activity or 75 minutes of vigorous- intensity physical activity per week, according to the World Health Organization (WHO) (WHO, 2015; Aceijas et al, 2017).

Physical activity aids in weight management, reduces the development of chronic diseases, and improves mental well-being when combined with an adequate and balanced nutrient intake. With so much evidence, it makes perfect sense to put student health at the top of the public health agenda by implementing appropriate strategies to prevent negative behaviours from developing. Several studies suggest that the transition to university life makes students susceptible to adopting those unhealthy behaviours (Deliens et al, 2015). Examples include the weight gain within the student population is substantially higher than in the equivalent population not attending universities (Vella-Zarb & Elgar, 2010). Rooted to the cause is insufficient physical activity and an unbalanced diet (Tsitsika et al, 2016). UK based research suggests students spend up to 8 hours a day on sedentary activities. Combined with dietary patterns that deteriorate with increases in fat, sodium and sugar intake, and suboptimal levels of fruit, vegetable, and whole grain consumption (Strong et al, 2008).

Some researchers suggest that while knowledge on what constitutes a balanced diet exists on campus, the problem is translating these into physical cooking and eating behaviours (Miles et al, 2016).

 © 2024 ARD Asociación Española

A study by Blake (2017) aimed at investigating the physical activity levels of UK nursing and medicine university students, examining predictors of physical activity and the most influential benefits and barriers to exercise to address this gap. Although nursing and medical students are taught about the health benefits of regular physical activity, this knowledge does not always translate into lifestyle choices (Blake et al, 2017). This is a critical issue: translating knowledge of the positive health outcomes associated with physical activity participation into sustained participation.

In particular, this research article is focused on physical activity participation and aims to identify the physical activity habits of university students in the UK, according to basic sociodemographic variables. The time devoted to different types of physical activity (light, moderate, vigorous), especially moderate-to-vigorous, will concentrate the scientific attention of this study.

METHODS

The current study employs a quantitative methodology with a cross-sectional design, a survey type, that uses data from questionnaires distributed online. Information regarding students' individual demographics and time students devoted to different types of physical activity were collected. University students (n = 465; mean age of 23.93 ± 4.83) located in the United Kingdom voluntarily accepted to participate in the current study. Participants were studying different academic levels (Undergraduate 71.9%, postgraduate 22.9% and PhD 5.2%) and came from different year of study (1st year 54.4%, 2nd year 31.3% and 3rd year 14.3%).

Participants were required to be full-time university students at any level (undergraduate, postgraduate and PhD) irrespective of year of study. Students attending subject specific universities or open university (dentistry, medical, chiropractic, ...etc) were also included. Exclusion was defined as attendees at non-English institutions such as foreign based schools with international campuses based in England, and international students studying Erasmus in England. In the current study, physical activity was assessed using the short form of the international Physical Activity Questionnaire (IPAQ) (Booth & Oja, 2003; Frederick & Evans, 2020). The 9-item instrument asks participants about their physical activity habits over the previous week. Participants reported their time allocation in four different categories of activity (vigorous-intensity, moderate-intensity, walking, and sitting) over the prior week. A definition of vigorous and moderate intensity activity was included for the ease of participants. Vigorous intensity was defined as "*activities that take hard physical effort and make you breathe much harder than normal"*. Moderate intensity was defined as "*activities that take moderate physical effort and make you breathe somewhat harder than normal*".

Demographic and self-reported IPAQ-SF descriptive statistics were computed. Participants had to have completed all the self-reported measures in order to be included in the study. SPSS software, version 28.0.1, was used for all statistical analyses. Participants were asked if they met the inclusion criteria (full-time university student at a UK faculty), and if so, then informed them by written consent that participation was voluntary, that all information was confidential, that no record of respondents' name would be made, and withdrawal was available at any point they wished to do so. If in agreement, the participant then completed the online survey (Lovell & Parker, 2010). This study was approved by the Ethics Committee of the Universitat de València, Spain.

Statistical analysis

Demographic and self-reported IPAQ-SF descriptive statistics were computed. Participants had to have completed all the self-reported measures in order to be included in the study. SPSS software, version 28.0.1, was used for all statistical analyses. For each UK university student, frequency counts, means, and standard deviations (SDs) were computed for the IPAQ-SF time values among the different items. A three-way ANOVA was used to determine differences between moderate and vigorous physical activity between the samples demographic variables under study.

RESULTS

A total of 466 participants partook in the current study, answering questions regarding individual demographics and physical activity habits (IPAQ-Short version). Participants' individual characteristics varied. A breakdown of the samples individual demographics can be viewed below in Table 1.

Table 1. Demographic of participants.

Variable	Male	(%)	Female	(%)
Global Value	147	30.6	305	63.5
Year of study				
1st Year	81	55.5	166	54.8
2nd Year	46	31.5	94	31.0
3rd Year	19	13.0	43	14.2
Socioeconomic level of family				
Over 3000£	96	63.5	209	68.5
Under 3000£	51	34.6	96	31.4
Living arrangement				
On campus	45	30.6	92	30.2
Off campus	102	69.4	213	69.8
Move away for study				
Yes	97	66.0	174	57.0
No	50	34.0	131	43.0

The current study uses the short form of the International Physical Activity Questionnaire (IPAQ- short version). The 9-items relate to participants' physical habits over the previous week. Participants then report their time allocation in four different categories of activity (vigorous, moderate, walking and sitting) over the past week. In Table 2 you can view the mean times performing light, moderate and vigorous physical activity between the university students in an average week while studying at university.

Table 2. Mean hours spent performing different physical activity categories.

Activity category	n	*Mean (SD)*
Light	466	1.1 (0.30)
Moderate	466	4.8 (0.52)
Vigorous	466	4.5 (0.60)
Moderate-vigorous	466	9.3 (1.10)

This data indicates that among university students in the United Kingdom, moderate forms of physical activity is performed for more time per week (4.85hrs) than those light (1.1hrs) or vigorous (4.5hrs) forms of physical activity. The mean time spent performing moderate- vigorous forms of physical activity was a mean of 9.35 hours per week. Lastly, concerning time spent sitting, students in the current study acknowledged sitting for a mean time of 4.32 ± 1.02 hours on an average weekday. You can observe those means in Table 3 below.

© 2024 ARD Asociación Española

Table 3. Mean of time spent sitting on a typical weekday by IPAQ physical activity category.

IPAQ Classification	Time spent sitting (hours)
Light	4.00 ± 1.14
Moderate	4.32 ± 0.99
Vigorous	4.58 ± 0.95
Moderate-vigorous	4.32 ± 1.02

A three-way ANOVA was conducted that examined the effect of gender, year of study and family monthly expenditure on vigorous physical activity participation. a significant interaction between gender and family monthly income on time spent doing vigorous physical activity on any given session per week was observed ($F = 7.383$, $p = .001$). Male participants reported a mean performance time (hours) of 1.53 ± 0.97, while female participants spent 1.42 ± 0.76 hours per session. A further significant interaction can be observed between gender and year of study ($F = 2.359$, $p = .031$) and time spent performing vigorous physical activity. With observed gender differences and vigorous physical activity performance, significance was also reported between year of study and time spent performing vigorous physical activity.

A further three-way ANOVA was performed to explore the effect gender, year of study and family monthly expenditure had on days and time spent performing moderate physical activity options on an average week. A statistically significant three-way interaction between gender, year of study and family monthly expenditure was observed ($F = 4.545$, $p = .004$) on days performing moderate physical activity. Additionally, a significant interaction ($F = 5.203$, $p = .006$) between year of study and family monthly income was reported with days performing moderate physical activity. Finally, the results of a further three-way ANOVA observed statistical significance between gender, year of study and family monthly expenditure on time spent performing moderate physical activity ($F = 4.206$, $p = .016$). Although no differences in time spent performing moderate physical activity were observed between genders or years of study.

DISCUSSION

Sufficient physical activity has a positive effect on participants' wellbeing and quality of life. University settings provide an important opportunity to advocate for positive physical activity behaviour in young adults worldwide. Despite this, there is a scarcity of data on those students' attitudes toward physical activity. The studies general physical activity categorisation of the sample according to the IPAQ short version was 64.4% moderately active, with a further 14.2% highly active. Notably, 18.2% were classified as being inactive. When it came to the physical activity category, there were gender differences with males performing more forms of vigorous physical activity than females. This is consistent with previous research indicating that males engage in more vigorous forms of physical activity and are generally more physically active than females (Thompson & Mirwald, 2003; El Ansari & Stock, 2022). The studies second objective was to determine the variation in UK university students MVPA according to gender, year of study and socioeconomic level of the family. Statistical significance was found within the relationship between gender and family monthly income and time spent performing vigorous forms of physical activity. In addition, there was a significant three-way relationship between gender, year of study, and family monthly income for time and days spent engaging in moderate physical activity.

Several variables have been found to differ in educational context and physical activity research. The current study gathered information on several variables that will be investigated in the following section. We wanted to position the main findings within the overall findings of physical activity level and observe the comparison to other research in this section. The current study found that moderate and vigorous forms of physical activity were performed on an average of 3.09 days per week. Moderate physical activity (mean of 1.57 hours) is performed for a longer period than vigorous forms (mean of 1.46 hours). Other studies using the IPAQ- SF found similar results in American college students (Dinger & Han, 2006; Kaleth & Tong, 2010), but significantly different results in Chinese and Portuguese populations when concerning days and time spent performing moderate and vigorous physical activity (Lee & Stewart, 2011; Romero-Blanco et al, 2020).

Regardless of how many hours the students in the sample sat on an average day at university (a mean of 4.32 hours on a typical weekday) 78.6% of the study sample was classified as moderately or highly active. In some populations, individuals who are highly active and participate in sports and exercise also have more sedentary time (Jago & Watson, 2005; Peterson & Erickson, 2018). Furthermore, evidence suggests that most individuals fall into one of only a couple commanding behaviour and activity level categories. Jago et al (2010) noted that a certain number of participants fit into one of three groups: high SB with high PA, moderate SB with low PA, and low SB with PA (Jago et al, 2010). Despite meeting the recommended daily physical activity guidelines, more than one-third of the adolescent and adult populations were classified as highly sedentary in a similar study involving both children and adults (Spittaels et al, 2012). According to these findings, individuals with high levels of physical activity in certain populations may also have high levels of Sedentary Behavior. Importantly, Ekelund et al (2016) discovered that moderate to vigorous physical activity can reduce all-cause mortality associated with sedentary behaviour; however, additional research on other factors such as disease morbidity and health-related quality of life may be required (Ekelund et al, 2016).Differences in physical activity habits according to gender, year of study and family socioeconomic status were reported in the current study. Gender differences in physical activity level, intensity and frequency are widely reported in this field (Bauman & Pratt, 2009; Azevedo & Hallal, 2007).

A longitudinal study by Naber & O'Brien carefully measured physical activity using accelerometers in male and female students aged 9 to 15 in a large geographically diverse population of US children with age and gender reported as highly influential in the MVPA levels throughout adolescence (Nader & O'Brien, 2008). Within the university population, these differences are observed, with differences in moderate and vigorous physical activity participation (Wilson & Bopp, 2022; Magoc & Bridges, 2016; Zhang & Chen, 2022). Individual differences were observed in the current study, which discovered a significant interaction between gender and time spent performing vigorous and moderate physical activity. Females made up 70% of first year inactive students in the current study. This data is consistent with other studies (Craike & Zimmermann, 2009; Reifsteck & Brooks, 2013) that show females have a significant drop-off in physical activity levels once they begin their college/university experience.

CONCLUSIONS

Universities in the United Kingdom interact with over 2.38 million students yearly, many of which are of an age that is susceptible to inactivity, poor diet and social pressures. University life consists of developing oneself within the educational environment along with developing social skills and dependency as an independent individual, learning to adapt to new environments, social circles and studies. The current study sought out to identify a set of objectives, the principal of which was to ascertain the physical activity levels of university students in the UK. The current study used the IPAQ-SF to categorise participants based on their physical activity habits. Most students fell within the moderate category (64.4%), while those categorised as high (14.2%) and low (18.5%) were the smaller outliers. The mean time spent performing "*light*" physical activity (1.1 hours) was substantially different compared to "*moderate*" (4.85 hours) and "*vigorous*" (4.5 hours) physical activity on an average university week. When examining the effect these variables had on a students'

 © 2024 ARD Asociación Española

physical activity level, it was noted that gender, year of study and family monthly income had an influence on students' physical activity levels.

However, the current results indicate that most students meet the "*moderate*" category for physical activity established by the IPAQ-SF, although it remains unclear what physical activity makes up the performance of those students. Nevertheless, universities and local institutions should strive to highlight the positive impact physical activity has on students' physical, social, and mental development. These adaptations will be based on the city's individual differences, acclimating such characteristics to encourage student participation in physical activity, embracing such activity as a means of social integration, social engagement, and environmental mapping, thereby facilitating integration into university life.

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

REFERENCES

Aceijas, C., Waldhäusl, S., Lambert, N., Cassar, S., & Bello-Corassa, R. (2017). Determinants of health-related lifestyles among university students. Perspectives in public health, 137(4), 227-236. https://doi.org/10.1177/1757913916666875

Andersen, L.B. and Haraldsdottir, J., 1993. Tracking of cardiovascular disease risk factors including maximal oxygen uptake and physical activity from late teenage to adulthood An 8-year follow-up study. Journal of internal medicine, 234(3), pp.309-315. https://doi.org/10.1111/j.1365-2796.1993.tb00748.x

Arriaza Jones, D., Ainsworth, B.E., Croft, J.B., Macera, C.A., Lloyd, E.E. and Yusuf, H.R., 1998. Moderate leisure-time physical activity: who is meeting the public health recommendations? A national cross-sectional study. Archives of family medicine, 7(3), p.285. https://doi.org/10.1001/archfami.7.3.285

Azevedo, M. R., Araújo, C. L. P., Reichert, F. F., Siqueira, F. V., da Silva, M. C., & Hallal, P. Baranowski, T., Thompson, W. O., Durant, R. H., Baranowski, J., & Puhl, J. (1993). Observations on physical activity in physical locations: Ager gender, ethnicity, and month effects. Research quarterly for exercise and sport, 64(2), 127-133. https://doi.org/10.1080/02701367.1993.10608789

Bauman, A., Bull, F., Chey, T., Craig, C. L., Ainsworth, B. E., Sallis, J. F., ... & Pratt, M. (2009). The international prevalence study on physical activity: results from 20 countries. International journal of behavioral nutrition and physical activity, 6(1), 1-11. https://doi.org/10.1186/1479-5868-6-21

Blake, H., Stanulewicz, N., & Mcgill, F. (2017). Predictors of physical activity and barriers to exercise in nursing and medical students. Journal of advanced nursing, 73(4), 917-929. https://doi.org/10.1111/jan.13181

Blanchard, C.M., McGannon, K.R., Spence, J.C., Rhodes, R.E., Nehl, E., Baker, F. and Bostwick, J., 2005. Social ecological correlates of physical activity in normal weight, overweight, and obese individuals. International journal of obesity, 29(6), pp.720-726. https://doi.org/10.1038/sj.ijo.0802927

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., ... & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. Medicine and science in sports and exercise, 35(8), 1381-1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Craike, C., Symons, C., & Zimmerman, J. (2009). Why do adolescent girls drop out of sport and physical activity? A social ecological approach. Annals of Leisure Research, 12(2), 149-172. https://doi.org/10.1080/11745398.2009.9686816

Deliens, T., Deforche, B., De Bourdeaudhuij, I., & Clarys, P. (2015). Determinants of physical activity and sedentary behaviour in university students: a qualitative study using focus group discussions. BMC public health, 15(1), 1-9. https://doi.org/10.1186/s12889-015-1553-4

Dinger, M. K., Behrens, T. K., & Han, J. L. (2006). Validity and reliability of the International Physical Activity Questionnaire in college students. American journal of health education, 37(6), 337-343. https://doi.org/10.1080/19325037.2006.10598924

Ekelund, U., Steene-Johannessen, J., Brown, W. J., Fagerland, M. W., Owen, N., Powell, K. E., El Ansari, W., Khalil, K., Crone, D., & Stock, C. (2022). Physical activity and gender differences: correlates of compliance with recommended levels of five forms of physical activity among students at nine universities in Libya.

El Ansari, W., Khalil, K., Crone, D., & Stock, C. (2022). Physical activity and gender differences: correlates of compliance with recommended levels of five forms of physical activity among students at nine universities in Libya.

El Gilany, A.H., Badawi, K., El Khawaga, G. and Awadalla, N., 2011. Physical activity profile of students in Mansoura University, Egypt. EMHJ-Eastern Mediterranean Health Journal, 17 (8), 694-702, 2011. https://doi.org/10.26719/2011.17.8.694

Engstrom, L.M., 1986. The process of socialization into keep fit activities. Scandinavian Journal of Sports Science, 8(3), pp.89-97.

Fagaras, S.P., Radu, L.E. and Vanvu, G., 2015. The level of physical activity of university students. Procedia-Social and Behavioral Sciences, 197, pp.1454-1457. https://doi.org/10.1016/j.sbspro.2015.07.094

Frederick, G. M., Castillo-Hernández, I. M., Williams, E. R., Singh, A. A., & Evans, E. M. (2020). Differences in physical activity and perceived benefits and barriers to physical activity between LGBTQ+ and non- LGBTQ+ college students. Journal of American College Health, 1-6. https://doi.org/10.1080/07448481.2020.1842426

Gangeness, J.E., 2010. Adaptations to achieve physical activity in rural communities. Western journal of nursing research, 32(3), pp.401-419. https://doi.org/10.1177/0193945909353767

Haase, A., Steptoe, A., Sallis, J.F. and Wardle, J., 2004. Leisure-time physical activity in university students from 23 countries: associations with health beliefs, risk awareness, and national economic development. Preventive medicine, 39(1), pp.182-190. https://doi.org/10.1016/j.ypmed.2004.01.028

Jago, R., Anderson, C. B., Baranowski, T., & Watson, K. (2005). Adolescent patterns of physical activity: Differences by gender, day, and time of day. American journal of preventive medicine, 28(5), 447-452. https://doi.org/10.1016/j.amepre.2005.02.007

Jago, R., Fox, K. R., Page, A. S., Brockman, R., & Thompson, J. L. (2010). Physical activity and sedentary behaviour typologies of 10-11 year olds. International Journal of Behavioral Nutrition and Physical Activity, 7, 59. https://doi.org/10.1186/1479-5868-7-59

Kaleth, A. S., Ang, D. C., Chakr, R., & Tong, Y. (2010). Validity and reliability of community health activities model program for seniors and short-form international physical activity questionnaire as physical activity assessment tools in patients with fibromyalgia. Disability and rehabilitation, 32(5), 353-359. https://doi.org/10.3109/09638280903166352

King, A.C., Castro, C., Wilcox, S., Eyler, A.A., Sallis, J.F. and Brownson, R.C., 2000. Personal and environmental factors associated with physical inactivity among different racial- ethnic groups of US middle- aged and older-aged women. Health psychology, 19(4), p.354. https://doi.org/10.1037//0278-6133.19.4.354

 © 2024 ARD Asociación Española

Kwan, M.Y., Cairney, J., Faulkner, G.E. and Pullenayegum, E.E., 2012. Physical activity and other health-risk behaviors during the transition into early adulthood: a longitudinal cohort study. American journal of preventive medicine, 42(1), pp.14-20. https://doi.org/10.1016/j.amepre.2011.08.026

Lee, P. H., Macfarlane, D. J., Lam, T. H., & Stewart, S. M. (2011). Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. International journal of behavioral nutrition and physical activity, 8(1), 1-11. https://doi.org/10.1186/1479-5868-8-115

Lovell, G. P., Ansari, W. E., & Parker, J. K. (2010). Perceived exercise benefits and barriers of non-exercising female university students in the United Kingdom. International Journal of Environmental Research and Public Health, 7(3), 784-798. https://doi.org/10.3390/ijerph7030784

Magoc, D., Tomaka, J., Shamaley, A. G., & Bridges, A. (2016). Gender differences in physical activity and related beliefs among Hispanic college students. Hispanic Journal of Behavioral Sciences, 38(2), 279-290. https://doi.org/10.1177/0739986316637355

Miles, C., & Benn, T. (2016). A case study on the experiences of university-based Muslim women in physical activity during their studies at one UK higher education institution. Sport, Education and Society, 21(5), 723- 740. https://doi.org/10.1080/13573322.2014.942623

Nader, P. R., Bradley, R. H., Houts, R. M., McRitchie, S. L., & O'Brien, M. (2008). Moderate- to-vigorous physical activity from ages 9 to 15 years. Jama, 300(3), 295-305. https://doi.org/10.1001/jama.300.3.295

Peterson, N. E., Sirard, J. R., Kulbok, P. A., DeBoer, M. D., & Erickson, J. M. (2018). Sedentary behavior and physical activity of young adult university students. Research in nursing & health, 41(1), 30-38. https://doi.org/10.1002/nur.21845

Reed, J. A., & Phillips, D. A. (2005). Relationships between physical activity and the proximity of exercise facilities and home exercise equipment used by undergraduate university students. Journal of American College Health, 53(6), 285-290. https://doi.org/10.3200/JACH.53.6.285-290

Reifsteck, E. J., Gill, D. L., & Brooks, D. L. (2013). The relationship between athletic identity and physical activity among former college athletes. Athletic Insight, 5(3), 271-284.

Romero-Blanco, C., Rodríguez-Almagro, J., Onieva-Zafra, M. D., Parra-Fernández, M. L., Prado-Laguna, M.D. C., & Hernández-Martínez, A. (2020). Physical activity and sedentary lifestyle in university students: changes during confinement due to the COVID-19 pandemic. International Journal of Environmental Research and Public Health, 17(18), 6567. https://doi.org/10.3390/ijerph17186567

Sigmundová, D., ChmelÍk, F., Sigmund, E., Feltlová, D. and Frömel, K., 2013. Physical activity in the lifestyle of Czech university students: Meeting health recommendations. European Journal of Sport Science, 13(6), pp.744-750. https://doi.org/10.1080/17461391.2013.776638

Spittaels, H., Van Cauwenberghe, E., Verbestel, V., De Meester, F., Van Dyck, D., Verloigne, M., ... & De Bourdeaudhuij, I. (2012). Objectively measured sedentary time and physical activity time across the lifespan: a cross-sectional study in four age groups. International Journal of Behavioral Nutrition and Physical Activity, 9(1), 1-12. https://doi.org/10.1186/1479-5868-9-149

Strong, K. A., Parks, S. L., Anderson, E., Winett, R., & Davy, B. M. (2008). Weight gain prevention: identifying theory-based targets for health behavior change in young adults. Journal of the American Dietetic Association, 108(10), 1708-1715. https://doi.org/10.1016/j.jada.2008.07.007

Thompson, A. M., Humbert, M. L., & Mirwald, R. L. (2003). A longitudinal study of the impact of childhood and adolescent physical activity experiences on adult physical activity perceptions and behaviors. Qualitative Health Research, 13(3), 358-377. https://doi.org/10.1177/1049732302250332

Tsitsika, A. K., Andrie, E. K., Psaltopoulou, T., Tzavara, C. K., Sergentanis, T. N., Ntanasis- Stathopoulos, I.,... & Tsolia, M. (2016). Association between problematic internet use, socio-demographic variables and obesity among European adolescents. The European Journal of Public Health, 26(4), 617-622. https://doi.org/10.1093/eurpub/ckw028

Vella-Zarb, R. A., & Elgar, F. J. (2010). Predicting the 'freshman 15': Environmental and psychological predictors of weight gain in first-year university students. Health Education Journal, 69(3), 321-332. https://doi.org/10.1177/0017896910369416

Vuori, I., 1995. Exercise and physical health: musculoskeletal health and functional capabilities. https://doi.org/10.1080/02701367.1995.10607912

Wilson, O. W., Panza, M. J., Evans, M. B., & Bopp, M. (2021). A scoping review on college student physical activity: How do researchers measure activity and examine inequities?. Journal of Physical Activity and Health, 18(6), 728-736. https://doi.org/10.1123/jpah.2020-0370

World Health Organisation (2010). Global recommendation on Physical activity for health.

World Health Organization (2015). Physical Activity Fact Sheet No. 385. World Health.

Zhang, Z., He, Z., & Chen, W. (2022). The relationship between physical activity intensity and subjective well-being in college students. Journal of American College Health, 70(4), 1241-1246. https://doi.org/10.1080/07448481.2020.1790575

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Effects of physical activity on levels of anxiety, depression, and stress during the social isolation caused by COVID-19

Maria Eduarda Cavalcante Félix. *Physical Education Department. State University of Paraíba. Paraíba, Brazil.*
Pedro Pinheiro Paes. *Physical Education Department. Federal University of Pernambuco. Pernambuco, Brazil.*
Marlene Salvina Fernandes da Costa. *Superior School of Physical Education. University of Pernambuco. Pernambuco, Brazil.*
Walmir Romário dos Santos. *School of Physical Education and Sport of Ribeirão Preto. University of São Paulo. São Paulo, Brazil.*
Wlaldemir Roberto dos Santos . *Physical Education Department. State University of Paraíba. Paraíba, Brazil.*
Superior School of Physical Education. University of Pernambuco. Pernambuco, Brazil.

ABSTRACT

COVID-19 is a disease caused by the SARS-CoV-2 virus, a new strain within the coronavirus family, which manifests itself in a varied and aggressive manner. The scenario of the COVID-19 pandemic has favored episodes of stress generated by prolonged isolation. Adherence to the practice of physical activity promotes beneficial effects on mental disorders, proving effective in this critical moment. The study's objective was to verify the effects of physical activity on levels of anxiety, stress, and depression during the period of social isolation. It is a cross-sectional study that identified the symptomatology of anxiety, stress, and depression, using the DASS-21. A total of 551 participants responded to the questionnaire online. The results showed that participants who did not engage in exercise before COVID-19 (n = 182) had higher levels of depression (p = .005), while those who engaged in physical activity (n = 323) showed lower indicators of anxiety (p = .010), stress (p = .021), and depression (p = .001). The study revealed that the frequent and continued practice of physical activity minimizes symptoms of anxiety, stress, and depression caused by the prolonged period of social isolation, favoring mental health benefits.
Keywords: Physical activity psychology, COVID-19, Mental health, Physical activity, Social isolation.

Cite this article as:
Cavalcante Félix, M. E., Pinheiro Paes, P., Fernandes da Costa, M. S., Romário dos Santos, W., & dos Santos, W. (2024). Effects of physical activity on levels of anxiety, depression, and stress during the social isolation caused by COVID-19. *Scientific Journal of Sport and Performance*, *3*(2), 261-269. https://doi.org/10.55860/SFNN2017

Corresponding author. *Superior School of Physical Education, University of Pernambuco. 310 Arnóbio Marques Street, Santo Amaro, Recife, PE 50100-130, Brazil.*
E-mail: wlaldemir.santos@upe.br
Submitted for publication January 30, 2024.
Accepted for publication March 01, 2024.
Published March 12, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/SFNN2017

INTRODUCTION

The coronavirus (COVID-19) had its initial records in China in December 2019. On February 25, 2020, the first case of COVID-19 was confirmed in Brazil. Progressing globally, it was declared a pandemic on March 11, 2020 (Dima et al., 2020). The disease is caused by the SARS-CoV-2 virus, a new strain within the coronavirus family. It presents in various forms, with symptoms ranging from mild to severe, where it is estimated that 20% of those affected require hospitalization and 5% require ventilatory support. In such cases, the virus damages the lower respiratory tract, manifesting as pneumonias. Severe respiratory manifestations are the highlight of the disease, following stages of cardiovascular disorder, altering and compromising blood clotting (Schuchmann et al., 2020; Santos et al., 2021).

The pandemic nature triggered urgent disease control measures. Additionally, epidemiological control measures, recommendations for social distancing, and isolation were adopted as effective alternatives in combating virus transmission (Guinancio et al., 2020).

Considering humans as socials beings, the need for interaction with others for personal and professional well-being is recognized by psychology and social sciences, essential for human formation and development (Guinancio et al., 2020; Wilder-Smith and Freedman, 2020). Aware of the complexity of human relationships and the fear of being infected by a lethal virus with a high transmission rate and an unknown treatment, social isolation and loneliness significantly increased the risk of anxiety and depression symptoms (Ribeiro et al., 2020).

Beyond mental health symptoms, the COVID-19 pandemic scenario favoured stress episodes, such as those resulting from prolonged isolation. The entirety of these factors directly compromised, whether in the short or long term, mental health (Galea et al., 2020). Considering the vulnerability of the immune system, the presence of negative emotions is a factor that weakens and promotes the threshold of feelings of anxiety, stress, and depression (Pereira et al., 2020).

The World Health Organization (WHO, 2020), in addressing strategies for coping with social isolation and its aftermath, advocates for a conscious consumption of information through reliable sources. This, coupled with a balanced diet and, most importantly, adherence to regular physical activity, is recommended due to its beneficial effects on mental disorders, as well as in the fight against chronic-degenerative diseases (cardiovascular disease, obesity, diabetes, hypertension) that put individuals in a fragile situation against the virus (Jiménez-Pavón et al., 2020).

According to WHO (2019) recommendations, a routine that includes continuous physical activity is a strong ally in the prevention and control of heart diseases, diabetes, cancer, and mental disorders (anxiety, stress, and depression), combating the decrease in cognitive loss, improving mental health, and enhancing people's quality of life. Unfortunately, the scenario of social isolation has hindered physical movement and reinforced a sedentary routine, the results of which will be felt soon. Through physical activity, we release a higher than usual number of neurotransmitters and hormones, such as endorphins, resulting in a reduction and almost negligible presence of depressive and anxious symptoms (Violant-Holz et al., 2020).

Thus, due to the magnitude of the COVID-19 pandemic and the necessity of social isolation, the mental health symptoms related to social isolation, and the promising effects of physical exercise on mental health are undeniable and recommended. Therefore, the present study aimed to investigate the effects of physical activity on levels of anxiety, stress, and depression during the COVID-19 social isolation period.

 © 2024 ARD Asociación Española

METHODOLOGY

Type of study and sample

This is a cross-sectional study with a qualitative approach. The sample consisted of 551 participants (182 males and 369 females) from 64 different cities across Brazil, selected through non-probabilistic, convenience, and adherence sampling. Inclusion criteria for the research required participants to be currently in isolation or to have remained in this condition for some time, and to respond to the online questionnaire in its entirety.

The procedures adopted in the study adhered to the guidelines of Resolution 466/12 of the National Health Council for research involving human subjects. The project obtained approval from the Ethics Committee on Human Research at the Federal University of Pernambuco, CAE No. 46978515.6.0000.5208.

Study design

Participants were invited to participate in the research through contact on social media platforms (Instagram, Facebook, Twitter, and WhatsApp). The invitation included an initial presentation about the research and an online questionnaire on the Google Forms platform. Upon accessing the form, participants read the Informed Consent Form (ICF), agreeing to the terms, ensuring anonymity, and the confidentiality of the data.

The questions were divided into sociodemographic aspects (age, gender, ethnicity, profession, city, state); physical activity practices before and during social isolation (frequency, duration, and intensity of these activities); COVID-19 diagnosis (current situation regarding social isolation, duration of isolation); concluding with the Anxiety, Depression, and Stress Scale – DASS 21 (Vignola, 2013). The questionnaire was available for 31 days (from June 29 to July 30, 2021).

To assess symptoms of anxiety, stress, and depression, the Anxiety, Depression, and Stress Scale-21 (DASS 21) adapted and validated for Brazilian Portuguese by Vignola (Vignola, 2013) was used. The DASS-21 consists of self-report subscales containing a set of three four-point Likert-type subscales (0, 1, 2, and 3). Each DASS-21 subscale comprises seven items designed to assess emotional states of anxiety, stress, and depression. The result is obtained by summing the scores of the items for each of the three subscales. The test involves the participant marking which statement applies to them over the past week. High scores on the DASS-21 serve as an alert to professionals, as they may indicate a high level of distress for the evaluated individual. The DASS-21 values were calculated using Cronbach's Alpha to ensure reliability, resulting in 0.92 for the Depression subscale, 0.90 for the Stress subscale, and 0.86 for the Anxiety subscale.

Statistical analysis

The data did not exhibit normality (Shapiro-Wilk) or variance homogeneity (Levene’s Test). Descriptive statistics for age (mean, standard deviation, minimum, and maximum), sample percentages, and gender-specific percentages indicating the occurrence of COVID-19, isolation, frequency, and level of physical activity were presented. The Mann-Whitney test for independent samples was employed to analyse the difference in median values of physical activity before COVID-19 and during isolation, as well as gender stratification by anxiety, stress, and depression. A 95% confidence interval was calculated for each variable. Data analysis was conducted using SPSS software, version 20.0 (IBM, USA), considering a significance level of 5% ($p < .05$).

RESULTS

A total of 551 volunteers participated in the study, with a mean age of 26.1 ± 7.8 years, divided by gender: female (n = 348), with a mean age of 26.3 ± 8.4 years, and male (n = 182), with a mean age of 25.6 ± 6.5 years.

Table 1. Median values of physical activity before COVID-19 and during isolation, stratified by gender and categorized by anxiety, stress, and depression.

Variables			***p*-value**
Physical Activity Before COVID-19	Group Yes (n = 323)	Group No (n = 228)	
Anxiety	5.0 ± 5.2	8.0 ± 5.6	.234
Stress	8.0 ± 5.4	11.0 ± 5.6	.569
Depression	6.0 ± 5.5	10.0 ± 6.2	.005*
Physical activity in isolation	Group Yes (n = 323)	Group No (n = 228)	
Anxiety	5.0 ± 5.1	7.0 ± 5.8	.010*
Stress	8.0 ± 5.3	9.5 ± 5.9	.021*
Depression	7.0 ± 5.4	8.0 ± 6.4	<.001*
Gender	Group Women (n = 348)	Group Men (n = 203)	
Anxiety	7.0 ± 5.5	3.0 ± 4.8	.005*
Stress	10.0 ± 5.4	7.0 ± 5.3	.348
Depression	8.0 ± 5.9	5.0 ± 5.4	.005*

*Note. *significant difference p < .05.*

Comparing participants who engaged in physical activity before COVID-19 (n = 323) and those who did not (n = 228), we observed higher levels of depression among those who did not engage in physical activity (*p* = .005). When comparing individuals who engaged in physical activity during the period of social isolation (coincidentally, also 323 participants practiced physical activity, and 228 did not), we observed a significant pattern of results for depression. We noted higher levels in the domains of anxiety (*p* = .010), stress (*p* = .021), and depression (*p* = .001) for those who did not engage in physical activity during the isolation period. When stratifying by gender, we observed that women statistically presented higher levels of anxiety (*p* = .005) and depression (*p* = .005) (Table 1).

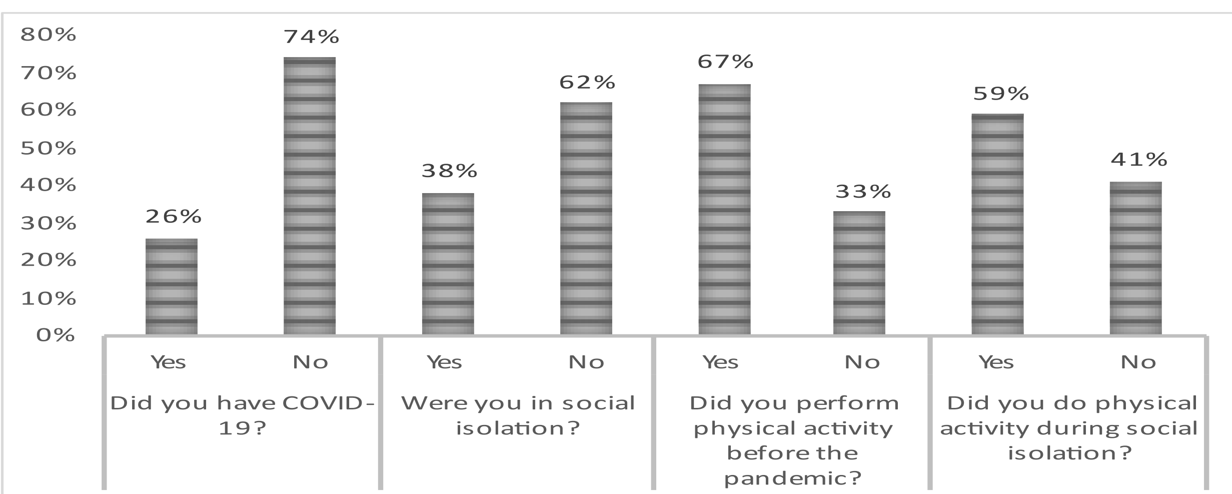


Figure 1. Percentages indicating the occurrence of COVID-19, social isolation, and physical activity practice.

 © 2024 ARD Asociación Española

Regarding the incidence of COVID-19 (Figure 1), the sample reveals that 26% of the participants reported having contracted the disease, with 64% of this group being women. Furthermore, 38% stated that they adhered to social isolation, with the majority being women (74%). Regarding physical activity before the pandemic, 67% of the participants claimed to engage in it, with women taking the lead at 56%. Surprisingly, during the period of social isolation, 59% indicated that they continued with their physical activities, with women predominantly represented in this group, totalling 52%.

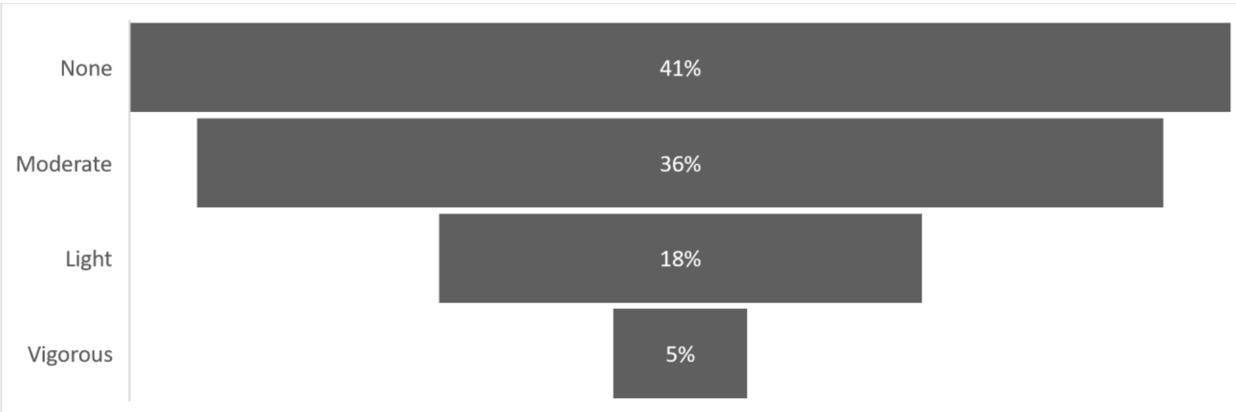


Figure 2. Percentages of reported high levels of physical activity.

Regarding the high level of physical activity reported by the subjects, it was observed that the majority who reported engaging in physical activity during social isolation did so with moderate intensity (36%), with a majority being women (59%). Additionally, 18% engaged in light activity, of which 74% were women, and only 5% participated in vigorous activity, with the majority being women (52%) (Figure 2).

DISCUSSION

This study aimed to investigate the effects of physical activity on levels of anxiety, stress, and depression during the COVID-19 social isolation period. The main findings of this investigation revealed that the group engaging in physical activity during the isolation period exhibited lower levels of anxiety, stress, and depression when compared to the group that did not engage in any physical activity. This aligns with the recommendation of the Brazilian Society of Sports Medicine and Exercise, emphasizing the importance of physical exercise as an alternative for improving immune function and the body's defences against infectious agents with pandemic transmission levels, such as COVID-19 (Júnior et al., 2020).

Additionally, Cardinal et al. (2015) emphasize the regularity of physical exercise as a preventive measure to enhance and boost immune function for the entire population, as a strategy to reduce anxiety and stress. Such measures, during periods of social isolation, should be undertaken by individuals not infected with COVID-19 or those exhibiting symptoms similar to the infection. Exercise should be suspended, even for those asymptomatic to the virus, and they should be promptly referred to a medical emergency unit.

However, certain recommendations must be followed and appropriately guided by professionals in the field. Jiménez-Pavón et al. (2020), in their study, suggest that during the social isolation period, physical exercises should be performed at home or in outdoor locations without crowds. The recommended frequency is five to seven times weekly, with the intercalation of intensity and volume levels of training to stimulate the cardiorespiratory system.

Upon analysing the sample by gender, it was observed that women significantly reported higher levels of anxiety (p = .005) and depression (p = .005). According to some studies (Lazarim, 2020; Loiola et al., 2020), women frequently experience depressive symptoms due to their involvement in dual, and often triple, work roles, juggling between paid employment, household chores, and childcare (Lazarim, 2020). Other contributing factors include emotional factors (mood swings, anxiety, and stress), biological conditions (reproductive period, pregnancy, and postpartum), and hormonal changes (PMS, perimenopause, and menopause). Given this scenario, it is evident that women tend to exhibit greater variations in anxiety, stress, and depression levels (Lazarim, 2020; Loiola et al., 2020).

In this perspective, physical exercise emerges as a non-pharmacological alternative for the treatment and maintenance of mental health, offering benefits in terms of hormonal regulation and the prevention of chronic-degenerative diseases (diabetes, hypertension, cardiovascular diseases, among others). It acts as a robust ally in combating mental disorders (Li et al., 2020).

Justifying the regular practice of physical activity during social isolation, the present study observed that the group maintaining physical exercise during this period showed lower levels of anxiety (p = .010), stress (p = .021), and depression (p = .001). Similarly, Corrêa et al. (2020) noted that maintaining exercise during the pandemic reduced symptoms of stress, anxiety, and depression. This observation aligns with findings from Cruz et al. (2021), who identified that the more active population has a 33.3% lower chance of presenting symptoms of anxiety and stress.

The mandatory social isolation combined with the fear of contracting a lethal virus (COVID-19) has led to a range of emotions in the population, mostly negative, such as anxiety, depression, and frustration. Additionally, the sense of uncertainty on a global scale, not only in health but also in the economic and financial aspects, adds concerns that impact positive emotions, such as feelings of joy, happiness, and the pleasure of living (Li, Wang, Xue, Zhao & Zhu, 2020).

Depression, classified as a psychiatric disorder, manifests in varying degrees (mild, moderate, and severe) with symptoms such as irritability, insomnia, and deep sadness. Characterized by mental and physical overload, family support plays a significant role in preventing the development of feelings of incapacity and demotivation, requiring medicinal intervention and specialized monitoring to avoid severe forms of the illness (Júnior et al., 2020). Sedentary behaviour, identified as the absence of physical activity, can be a concerning risk factor for mental health. However, regular physical activity, in many cases, mitigates the effects of mental disorders (Ferreira et al., 2020). In the same vein, the present study highlighted higher levels of depression (p = .005) in subjects who did not engage in physical activity.

It is undeniable that the COVID-19 pandemic has become a focal point of study for healthcare professionals, and devising effective strategies to combat and prevent the disease has been a considerable challenge. However, physical health measures, implemented through physical exercise, have proven to be the most effective contribution during this period, positively impacting psychological well-being during isolation and social distancing, making it less detrimental (Wang et al., 2020).

Based on these findings, it is evident that regular physical activity plays a significant role in alleviating depressive symptoms (Maciel et al., 2021; Matsudo et al., 2020), in addition to promoting physical well-being. Therefore, maintaining levels of physical activity during social isolation is suggested as a preventive measure to support mental health, reducing levels of anxiety, stress, and depression (Matsudo et al., 2020; WHO, 2020).

 © 2024 ARD Asociación Española

CONCLUSION

Based on the findings of the present study, we conclude that engaging in physical activity should occur frequently and consistently to minimize symptoms of anxiety, stress, and depression caused by the prolonged period of social isolation, thereby promoting mental health benefits and improving overall quality of life. It is important to emphasize that physical exercise plays a fundamental role in physical well-being, with these benefits extending to the treatment and care of mental health. However, the pandemic-induced isolation marked an unprecedented and unpredictable period. Some limitations were reported in the investigation, such as the self-reported level of physical activity, the understanding of different activity levels indicated by the sample, and the lack of experimentation with remotely supervised physical exercise for the group engaging in physical activity during the social isolation period. Therefore, we suggest that studies highlighting the practice of exercise as a supportive effect in post-COVID-19 pandemic treatment be further explored to measure the consequences of this unfortunate occurrence, which brought about numerous changes in the daily lives of people worldwide.

AUTHOR CONTRIBUTIONS

Research design, data collection, data analysis, and text writing: Félix, M. E. C.; Santos, W. R. Results analysis and text writing: Paes, P. P.; Costa, M. S. F.; Santos, Walmir R. Text revision and translation: Santos, W. R.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Corrêa, C. A., Verlengia, R., Ribeiro, A. G. S. V., & Crisp, A. H. (2020). Níveis de estresse, ansiedade, depressão e fatores associados durante a pandemia de COVID-19 em praticantes de Yoga. Revista Brasileira de Atividade Física & Saúde, 25, 1-7. https://doi.org/10.12820/rbafs.25e0118

Cruz, L. M. C., Pires, M. M., Reis, V. M. N., Chaves, A. D., & Nacimento, C. A. C. (2021). Prática de exercício físico, ingestão alimentar e estado de ansiedade/estresse de participantes do projeto MOVIP em meio à pandemia de COVID-19. HU Revista, 47, 1-6. https://doi.org/10.34019/1982-8047.2021.v47.32209

Dima, A., Balaban, D. V., Jurcut, C., Berza, I., Jurcut, R., & Jinga, M. (2021). Perceptions of Romanian physicians on lockdowns for Covid-19 prevention. Healthcare, 9(1), 95https://doi.org/10.3390/healthcare9010095

Ferreira, A. L., Fontinele, V. R., de Melo, G. F., & Vilaça, K. H. C. (2020). Orientações de exercício físico em mídias digitais para idosos durante o isolamento social ocasionado pela COVID-19. Revista Kairós-Gerontologia, 23, 687-705.

Galea, S., Merchant, R. M., & Lurie, N. (2020). The mental health consequences of COVID-19 and physical distancing: the need for prevention and early intervention. JAMA internal medicine, 180(6), 817-818. https://doi.org/10.1001/jamainternmed.2020.1562

Gomes, A., Ramos, S., Ferreira, A. R., Montalvão, J., Carvalho Ribeiro, I. M. O., & Lima, F. (2019). A efetividade do exercício físico no tratamento da depressão. Revista Portuguesa de Enfermagem de Saúde Mental, (22), 58-64. https://doi.org/10.19131/rpesm.0264

Guinancio, J. C., de Sousa, J. G. M., de Carvalho, B. L., de Souza, A. B. T., de Araujo Franco, A., de Almeida Floriano, A., & Ribeiro, W. A. (2020). COVID-19: Desafios do cotidiano e estratégias de enfrentamento frente ao isolamento social. Research, Society and Development, 9(8), e259985474-e259985474. https://doi.org/10.33448/rsd-v9i8.5474

Jiménez-Pavón, D., Carbonell-Baeza, A., & Lavie, C. J. (2020). Physical exercise as therapy to fight against the mental and physical consequences of COVID-19 quarantine: Special focus in older people. Progress in cardiovascular diseases, 63(3), 386. https://doi.org/10.1016/j.pcad.2020.03.009

Cardinal, B. J., Park, E. A., Kim, M., & Cardinal, M. K. (2015). If exercise is medicine, where is exercise in medicine? Review of US medical education curricula for physical activity-related content. Journal of Physical Activity and Health, 12(9), 1336-1343. https://doi.org/10.1123/jpah.2014-0316

Júnior, P. G. F., Paiano, R., & dos Santos Costa, A. (2020). Isolamento social: consequências físicas e mentais da inatividade física em crianças e adolescentes. Revista Brasileira de Atividade Física & Saúde, 25, 1-2. https://doi.org/10.12820/rbafs.25e0115

Lazarim, C. A. P. (2020). Entre a casa e a escola: a dupla jornada de mulheres-professoras. Seminário Virtual da Mulher. Retrieved from [Accessed March 01, 2024]: https://anais.eventos.iff.edu.br/index.php/svmulher/article/view/33

Li, S., Wang, Y., Xue, J., Zhao, N., & Zhu, T. (2020). The impact of COVID-19 epidemic declaration on psychological consequences: a study on active Weibo users. International journal of environmental research and public health, 17(6), 2032. https://doi.org/10.3390/ijerph17062032

Loiola, E. F., Costa, B. C., Oliveira, K. L. X., & Borges, L. D. A. R. (2020). Transtornos Mentais Evidentes no Sexo Feminino. Revista Científica da Faculdade de Medicina de Campos, 15(3), 72-76. https://doi.org/10.29184/1980-7813.rcfmc.369.vol.15.n3.2020

Maciel, H. C. R., Hosken, C. L., & Ramos, I. D. S. F. (2021, September). Bem Estar e Isolamento Social: como a pandemia afeta a saúde mental dos brasileiros. In Anais do Congresso Nacional Universidade, EAD e Software Livre (Vol. 2, No. 12).

Matsudo, V. K. R., dos Santos, M., & de Oliveira, L. C. (2020). Quarentena sim! Sedentarismo não! Atividade física em tempos de coronavírus. Diagnóstico e Tratamento, 25(3), 116-120. Retrieved from [Accessed March 01, 2024]: https://docs.bvsalud.org/biblioref/2020/11/1129416/rdt_v25n3_116-120.pdf

Pereira, M. D., de Oliveira, L. C., Costa, C. F. T., de Oliveira Bezerra, C. M., Pereira, M. D., dos Santos, C. K. A., & Dantas, E. H. M. (2020). A pandemia de COVID-19, o isolamento social, consequências na saúde mental e estratégias de enfrentamento: uma revisão integrativa. Research, Society and development, 9(7), e652974548-e652974548. https://doi.org/10.33448/rsd-v9i7.4548

Ribeiro, Í. A. P., da Rocha, M. O., Cunha, D. C. L., da Silva Araújo, A., Amaral, I. N., Marques, L. L., & Cunha, M. B. (2020). Isolamento social em tempos de pandemia por COVID-19: impactos na saúde mental da população. Revista Enfermagem Atual In Derme, 92(30). https://doi.org/10.31011/reaid-2020-v.92-n.30-art.741

Santos, N. K., Baptista, L. H. P., da Silva Triani, F., Monteiro, E. R., & Neto, V. G. C. (2021). Análise do nível de atividade física e ansiedade durante o isolamento social no período de pandemia. BIOMOTRIZ, 15(1), 61-71. https://doi.org/10.33053/biomotriz.v15i1.422

Schuchmann, A. Z., Schnorrenberger, B. L., Chiquetti, M. E., Gaiki, R. S., Raimann, B. W., & Maeyama, M. A. (2020). Isolamento social vertical X Isolamento social horizontal: os dilemas sanitários e sociais no enfrentamento da pandemia de COVID-19. Brazilian Journal of Health Review, 3(2), 3556-3576. https://doi.org/10.34119/bjhrv3n2-185

 © 2024 ARD Asociación Española

Vignola, R. C. B. (2013). Escala de depressão, ansiedade e estresse (DASS): adaptação e validação para o português do Brasil. Retrieved from [Accessed March 01, 2024]: http://repositorio.unifesp.br/handle/11600/48328

Violant-Holz, V., Gallego-Jiménez, M. G., González-González, C. S., Muñoz-Violant, S., Rodríguez, M. J., Sansano-Nadal, O., & Guerra-Balic, M. (2020). Psychological health and physical activity levels during the COVID-19 pandemic: a systematic review. International journal of environmental research and public health, 17(24), 9419. https://doi.org/10.3390/ijerph17249419

Wang, C., Pan, R., Wan, X., Tan, Y., Xu, L., Ho, C. S., & Ho, R. C. (2020). Immediate psychological responses and associated factors during the initial stage of the 2019 coronavirus disease (COVID-19) epidemic among the general population in China. International journal of environmental research and public health, 17(5), 1729. https://doi.org/10.3390/ijerph17051729

Wilder-Smith, A., & Freedman, D. O. (2020). Isolation, quarantine, social distancing and community containment: pivotal role for old-style public health measures in the novel coronavirus (2019-nCoV) outbreak. Journal of travel medicine, 27(2), taaa020. https://doi.org/10.1093/jtm/taaa020

World Health Organization. (2019). Considerations for implementing and adjusting public health and social measures in the context of COVID-19: interim guidance, 4 November 2020 (No. WHO/2019-nCoV/Adjusting_PH_measures/2020.2). World Health Organization. Retrieved from [Accessed March 01, 2024]: https://apps.who.int/iris/handle/10665/336374

World Health Organization (WHO). 2020. WHO Guidelines on physical activity and sedentary behaviour: at a glance. Retrieved from [Accessed March 01, 2024]: https://outrightinternational.org/content/world-health-organizations-says-being-trans-not-mental-disorder?gclid=CjwKCAiA0KmPBhBqEiwAJqKK47t7zRhhDuQDtAz5EuSz8u7EfkzZj6sQI5-Gt8-ZDp6MYZGIh-vFKBoChCsQAvD_BwE

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

User perception and acceptance of softshell headgear amongst youth rugby players

Annette Gail Heward-Swale. *Department of Mechanical Engineering. University of Canterbury. Christchurch, New Zealand.*
Natalia Kabaliuk ✉ **.** *Department of Mechanical Engineering. University of Canterbury. Christchurch, New Zealand.*
Nicole Spriggs. *Department of Tourism Sport & Society. Lincoln University. Lincoln, New Zealand.*
Stefan Henley. *School of Health Sciences. Faculty of Health. University of Canterbury. Christchurch, New Zealand.*
Michael Hamlin. *Department of Tourism Sport & Society. Lincoln University. Lincoln, New Zealand.*
Nick Draper. *School of Health Sciences. Faculty of Health. University of Canterbury. Christchurch, New Zealand.*

ABSTRACT

This study investigated the attitudes, preferences, motivations and acceptance of softshell headgear among youth rugby players. Female and male rugby players (ages 13-17) were surveyed regarding headgear use during training and matches, discontinuation reasons, preferred brands, motivations for use, and reasons for non-use. We assessed confidence without headgear, head injuries, familiarity with specifications, and awareness of benefits/risks. Most (86%) didn't wear headgear during training; 74.4% abstained in matches. Reasons for discontinuation included discomfort and perceived ineffectiveness. Parental advice (78%) and injury protection (52%) drove headgear use. Non-use reasons: lack of ventilation (67%), bulkiness (50%), discomfort (44%), non-compulsory use (36%), and lack of consideration (36%). 44.2% believed headgear protects against head injuries; 30.2% were unsure. The results of this study indicate a range of attitudes among youth rugby players towards the use of headgear. Understanding their motivations and concerns is crucial for improving player safety. While some players see headgear as a valuable protective measure, others are deterred by factors such as discomfort and lack of ventilation. There is a need for greater awareness and education about headgear benefits and risks among rugby players, potential modifications to headgear design to enhance comfort and ventilation should be explored and further research conducted to explore the benefits that headgear has for head impact protection.
Keywords: Physical activity psychology, Head injuries, Sports science, Sport and exercise, Protective equipment, Rugby safety, Player attitudes.

Cite this article as:
Heward-Swale, A. G., Kabaliuk, N., Spriggs, N., Henley, S., Hamlin, M., & Draper, N. (2024). User perception and acceptance of softshell headgear amongst youth rugby players. *Scientific Journal of Sport and Performance*, *3*(2), 270-281. https://doi.org/10.55860/TWPZ7832

✉ **Corresponding author.** *Department of Mechanical Engineering. University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand.*
E-mail: natalia.kabaliuk@canterbury.ac.nz
Submitted for publication February 04, 2024.
Accepted for publication March 04, 2024.
Published March 12, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/TWPZ7832

© 2024 ARD Asociación Española

INTRODUCTION

Rugby, a dynamic and widely embraced contact sport, has experienced remarkable global growth, boasting participation from over 7.6 million players in more than 128 countries (World Rugby, 2021). The substantial numbers of registered players, both worldwide and in specific regions like New Zealand, underscore the sport's universal appeal. Studies have identified a positive correlation between rugby's popularity and increased media coverage, strengthened safety regulations, and the establishment of community youth programmes in rugby (King et al., 2009; New Zealand Rugby, 2023; Quarrie et al., 2020; World Rugby, 2021). In nations like New Zealand, where the population is around five million, the robust engagement of over 160,000 players highlights the sport's profound popularity at the grassroots level (New Zealand Rugby, 2023). However, the current body of literature addressing rugby at the youth and community levels is notably limited (Freitag et al., 2016).

In the context of rugby, a sport demanding physical prowess and marked by high competitiveness, the risk of injuries, particularly those affecting the head, has become a focal point. In the pursuit of player safety, the sport has evolved, with protective equipment playing a pivotal role in injury prevention. Softshell headgear, a notable addition to protective gear, has garnered attention in recent years (King et al., 2016).

Within the landscape of youth rugby, understanding the attitudes and acceptance of softshell headgear becomes crucial. The safety of young athletes is paramount, and comprehending their preferences, motivations, and concerns regarding headgear usage is of utmost importance (Freitag et al., 2016).

A systematic review of strategies aimed at preventing concussions determined that while headgear may effectively reduce superficial head injuries, it does not offer protection against concussions (Schneider et al., 2017). However, studies indicate that a noteworthy percentage of players, as high as 60%, maintain the belief that wearing headgear can prevent serious head injuries, including concussions (Finch et al., 2001; Menger et al., 2016; Pettersen, 2002). While strides have been made in improving headgear designs and materials, understanding how youth players perceive and accept this equipment is a critical aspect of rugby safety (King et al., 2016). This study delves into the attitudes and perceptions held by high school-level youth rugby players towards softshell headgear. This study aims to explore the preferences, choices, and beliefs of youth rugby players regarding softshell headgear. It investigates usage patterns during training sessions and matches, reasons for discontinuing headgear use, brand preferences, and motivating factors for both wearing and not wearing headgear (Fuller et al., 2017; Makovec Knight et al., 2021; Pfister et al., 2016).

The novelty of this research lies in its specific focus on high school-level youth rugby players and their perceptions of softshell headgear. The unique characteristics and concerns of younger athletes may significantly differ from those of adults (Freitag et al., 2016). By bridging this knowledge gap, this study seeks to provide insights that can inform decision-makers, coaches, and parents about safety measures deemed effective and acceptable by youth players in rugby (Quarrie et al., 2020; Silver et al., 2018).

As youth rugby continues to gain popularity, striking a balance between player engagement and maintaining a safe playing environment is essential. This research, by delving into the nuanced world of youth rugby players' attitudes towards softshell headgear, aims to contribute to the development of strategies that not only reduce the risk of head injuries but also enhance the overall safety and well-being of these young athletes (Quarrie et al., 2001).

MATERIAL AND METHODS

Ethics approval and informed consent

This research received ethical approval from the University of Canterbury Human Research Ethics Committee (HEC 2021/26) and all procedures were conducted in accordance with relevant ethical standards and regulations. This research adhered to ethical guidelines, with the informed consent of participants and respect for their privacy. The data collected were anonymised to protect the identities of the participants.

Study participants

A total of 43 high school-level rugby players, including both females (aged 13-17 years) and males (aged 14-16 years), participated in this study. The female participants were 1st and 2nd XV rugby players drawn from one high school. The male participants were Under16 club rugby players drawn from three different high schools. The participants reflected a mix of rugby experiences, and backgrounds.

Survey method

To assess the attitudes and acceptance of softshell headgear among the youth rugby players, a structured questionnaire was developed. The questionnaire aimed to capture a comprehensive overview of the participants' perspectives regarding headgear usage. The questions were designed to explore various aspects, including the frequency of headgear use during training sessions and matches, past experiences with headgear, reasons for discontinuing its use, preferred headgear brands, motivating factors for using or not using headgear, belief in the efficacy of headgear, confidence in head protection without headgear, history of head injuries, familiarity with headgear specifications and regulations, and perceptions of the availability of information regarding headgear benefits and risks.

Table 1. Survey questions.

Questions
Do you wear headgear during rugby training sessions?
Do you wear headgear during rugby gameplay (matches)?
If you DO NOT wear headgear have you worn it in the past?
If you answered YES to the above question, why did you stop using headgear?
If you have ever worn headgear, what brand/s of headgear have you worn?
For those who wear headgear: What are the primary reasons for choosing to wear headgear during rugby activities?
Please select your preferred brand/s of headgear to wear:
For those who DO NOT wear headgear: What are the main reasons for choosing not to wear headgear during rugby activities?
Related to the above question, are there other specific concerns or disadvantages you associate with headgear that influence your decision not to wear it?
Do you believe that headgear offers protection against potential head injuries?
Please explain your above answer about whether you believe that headgear offers protection against potential head injuries?
How confident are you in your head protection without wearing headgear?
Have you experienced any head injuries while playing rugby, and if so, how severe were they?
Have you had a concussion while playing rugby this season?
How familiar are you with the specifications and regulations regarding headgear in rugby?
Do you think there is enough information available to players about the benefits of wearing headgear and/or the risks of not wearing headgear?
Is there anything specific that could be done to make headgear more appealing or effective for rugby players?
Please explain your above answer in regards to potential improvements to headgear.
If there is anything else you'd like to share about your decision to wear or not wear headgear in rugby, please do so.

 © 2024 ARD Asociación Española

The majority of attitudinal and knowledge data were captured through questions using a five-point Likert scale. Survey questions related to reasons for wearing or not wearing headgear, as well as questions about favourable headgear design and features, presented a set of options for participants to select the most fitting responses. The wording for these attitudinal and opinion-based questions, along with their corresponding options, is outlined in Table 1.

The questionnaire was administered to the participants through majority in-person surveys but due to accessibility issues two participants completed the questionnaire online. Participants were provided with clear instructions on how to complete the questionnaire. Data collection was conducted in an ethical manner, ensuring that all participants provided informed consent before participating in the study. The data collection process aimed to be inclusive and non-intrusive, acknowledging the sensitivity of the topic.

Statistical analyses

The data obtained from the completed questionnaires was analysed using descriptive statistics. The responses were collated and summarised to provide an overall view of the participants' attitudes towards softshell headgear. These statistics included percentages, counts, and proportions that helped identify patterns and trends in the participants' responses.

Limitations

It is essential to acknowledge potential limitations in the methods employed in this study. The sample size of 43 participants, while diverse, may not be fully representative of all youth rugby players, and the findings may not be generalisable to all populations. Additionally, the use of a structured questionnaire, while allowing for quantitative analysis, may not capture the full spectrum of qualitative insights that participants may have regarding headgear usage. It is important to note that the questionnaire did allow for participants to comment and add in other options to the structured list of answers in various question sections.

Overall, the methods used in this study aimed to comprehensively assess the attitudes and acceptance of softshell headgear among high school-level youth rugby players. The structured questionnaire provided a structured approach to gathering information from participants, allowing for the quantitative analysis of their responses. These methods, while not without limitations, were chosen to ensure the ethical conduct of the study and the extraction of valuable insights into this crucial aspect of player safety in youth rugby.

Data availability

Raw data were generated at the Department of Mechanical Engineering at the University of Canterbury. Data generated during this study are available from the corresponding author upon reasonable request. The data are not publicly available to protect the privacy of the players involved.

RESULTS

All 43 study participants completed the survey. 41 participants were taken through the survey in-person with one of the researchers. Two participants completed the survey online, without the supervision of one of the researchers.

Uptake of headgear use

Data from the questionnaire responses were analysed using descriptive statistics, and the results are presented below. Among the participants, 37 (86%) did not wear headgear during training sessions, with 3

(7%) using headgear occasionally and 3 (7%) using headgear consistently. In matches, 32 (74%) did not wear headgear, 3 (7%) used headgear occasionally, and 8 (18.6%) used headgear consistently.

Reasons for wearing headgear

Of those who previously wore headgear but stopped (14 participants), reasons included discomfort, a perception that headgear was not needed, and that headgear was bulky/annoying. Some participants reported that various brands of headgear were used, with CCC (Canterbury of New Zealand) being the most common (12 participants), followed by NPro (Contego Sports Ltd., approved by World Rugby Trial WRX-286-IKY), (9 participants).

For those who have worn headgear at any stage, the primary reasons (chosen from any of ten options) included parental advice (19 respondents), protection from head injuries (12), protection from scratches/cauliflower ear (8), and feeling safer when wearing headgear (7). See Figure 1.

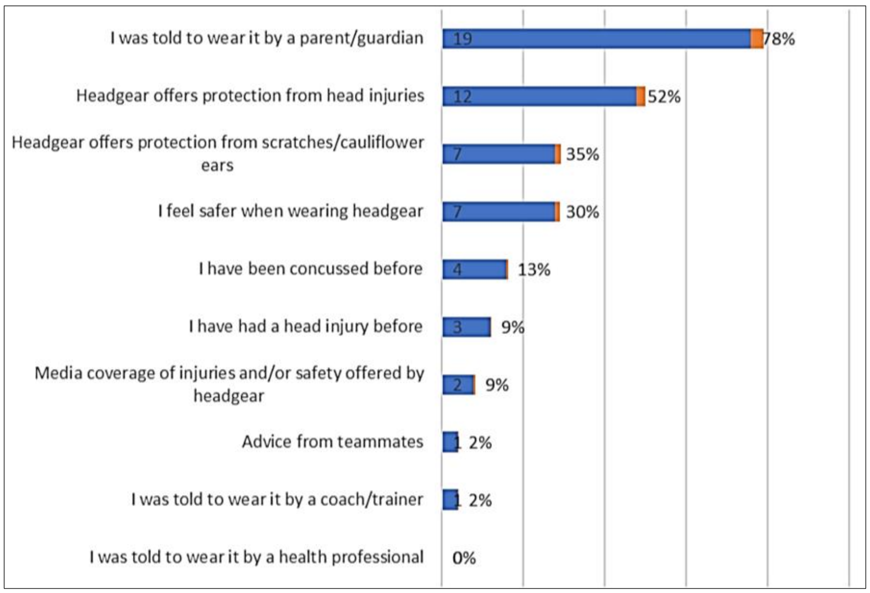


Figure 1. Primary reasons for wearing headgear (23 respondents).

Reasons for not wearing headgear

The primary reasons for not wearing headgear as shown in Figure 2 were lack of ventilation (24 respondents), headgear being bulky and annoying (18), general discomfort (16), headgear not being compulsory (13), not considering wearing headgear (13), headgear appearance was undesirable (12), the perception that headgear was not needed (12). Also cited was headgear being a barrier to hearing (9) and headgear not fitting properly (6) as reasons. Headgear restricting mobility (3) and the cost of headgear (3) were also mentioned.

Efficacy of headgear

In terms of belief in headgear efficacy in head protection, 44% believed that headgear offers protection against potential head injuries, while 26% did not, and 30% were unsure.

In assessing their confidence in head protection without wearing headgear, the majority of participants expressed confidence, 16% were completely confident, 49% were very confident, 5% were somewhat confident, only 2% were not confident at all, and 28% were neutral (see Figure 3).

 © 2024 ARD Asociación Española

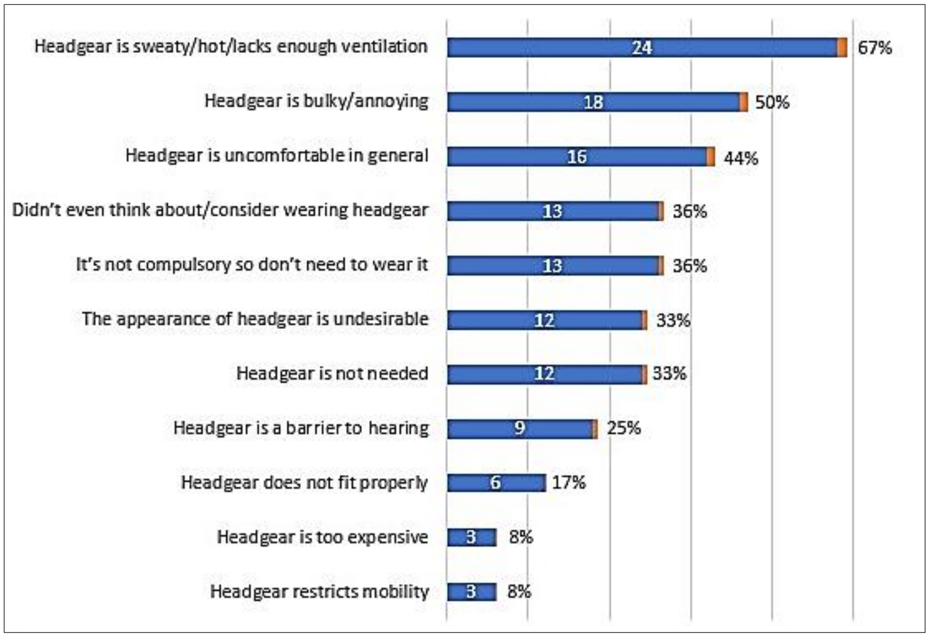


Figure 2. Primary reasons for not wearing headgear (36 respondents).

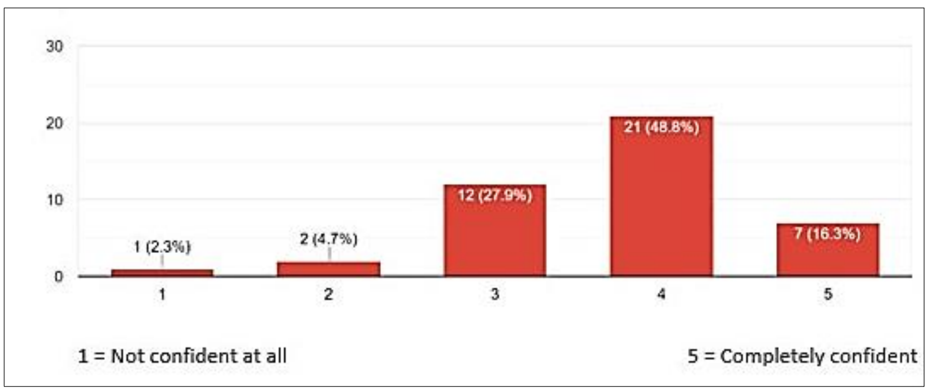


Figure 3. Player level of confidence in head protection without wearing headgear.

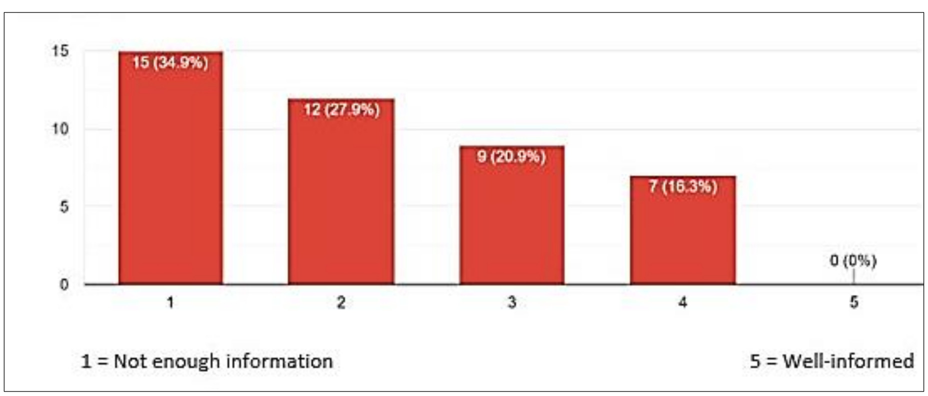


Figure 4. Scale of perceived amount of information available to players, about the benefits of wearing headgear and/or the risks of not wearing headgear.

Head injuries

Regarding whether the players had experienced any head injuries while playing rugby, 25 (58%) participants reported no head injuries, (9) 20% had mild head injuries, 6 (14%) had moderate head injuries, 4 (9%) had significant head injuries, and 1 (2%) had experienced a serious head injury. It should be noted that 2 players each reported on 2 different head injuries (at different severity levels). No players reported having experienced severe head injuries.

Information availability

In terms of familiarity with the specifications and regulations regarding headgear in rugby, 77% (33 out of 43 participants) were not familiar at all, 12% were somewhat familiar, 7% were neutral, 2% were familiar, and 2% felt they were extremely familiar.

Participants' perceptions of information availability about the benefits and risks of headgear varied (see Figure 4): 35% felt there was not enough information available, 28% thought there was somewhat enough information, 21% were neutral, and 16% believed there was information available. None reported having a lot of information.

Making headgear more appealing or effective

Suggestions by participants for making headgear more appealing or effective (Figure 5) included increasing ventilation (79%), better hearing access (42%), improving design for proper fitting (33%), making it more affordable (26%), making headgear less stiff/rigid (26%), using a thicker shell (19%), using a thinner shell (16%), and making headgear compulsory under World Rugby rules (16%). Four participants (9%) indicated that no specific changes were needed.

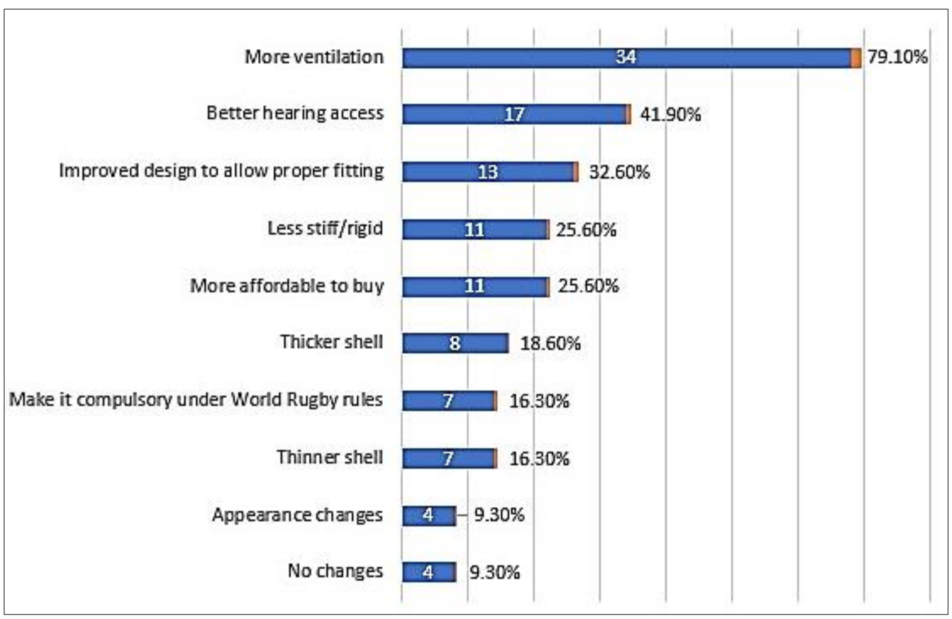


Figure 5. Player suggestions on how headgear could be more appealing or effective (43 respondents).

DISCUSSION

In exploring the growth of rugby at the youth and community levels, our findings present crucial points for discussion, particularly when compared to existing research. Our study also highlights a noticeable gap in

 © 2024 ARD Asociación Española

the literature concerning youth and community rugby. While research has addressed safety concerns at the professional level, the dearth of comprehensive studies focused on grassroots rugby is evident (Freitag et al., 2016; Quarrie et al., 2001). This emphasises the urgency for targeted research in these demographics to provide a nuanced understanding of safety dynamics (Freitag et al., 2016).

The lack of information surrounding the benefits to wearing headgear and the risks of not wearing headgear, and the adequacy of safety education, resonate with the broader discourse in rugby safety research. Studies have highlighted similar concerns, indicating a need for standardised safety protocols and comprehensive educational initiatives across all levels of play (Fuller et al., 2017; King et al., 2016).

Furthermore, our study aligns with Quarrie, Gianotti, and Murphy's (2020) investigation into injury risks in New Zealand Rugby Union. Their nationwide study of injury insurance claims from 2005 to 2017 complements our findings, highlighting the need for a comprehensive approach to injury prevention at the grassroots level (Quarrie et al., 2020). Additionally, the prospective cohort study by Quarrie et al. (2001) on risk factors for injury in rugby union football adds depth to our understanding of injury dynamics in community rugby. Their research supports the notion that a holistic approach, considering player-specific factors, is essential for mitigating injury risks (Quarrie et al., 2001).

In summary, our study contributes valuable insights into the safety concerns associated with the growth of rugby at the youth and community levels. While our findings align with broader trends identified in existing research, the specificity of our focus on grassroots rugby illuminates unique challenges that warrant dedicated attention. Future research should build upon these comparative insights to develop targeted interventions and safety strategies that align with the distinct characteristics of youth and community rugby. By doing so, we can collectively work towards ensuring that the burgeoning enthusiasm for the sport of rugby is met with robust safety measures at every level of play.

CONCLUSIONS

This study has shed light on the complex and varied attitudes of youth rugby players towards the use of softshell headgear. It is evident that there is no one-size-fits-all perspective on this protective equipment. While some players view headgear as a valuable safeguard against head injuries, others are deterred by the discomfort and lack of ventilation it may bring. These contrasting opinions highlight the need for a nuanced understanding of the factors that influence players' decisions regarding headgear usage.

The findings underscore the importance of addressing these multifaceted attitudes in the context of youth rugby. Player safety is a paramount concern, and the efficacy of protective equipment is contingent on players' willingness to wear it. A comprehensive understanding of the factors influencing player choices can inform strategies for injury prevention and safety enhancement in the sport.

Increasing awareness and education about the benefits and risks associated with headgear is an imperative step towards mitigating the misconceptions and uncertainties prevalent among young rugby players. Many players are unsure about the protective qualities of headgear, and a significant portion believes that it does not offer the protection it claims to provide. Clarifying these aspects through education and information dissemination can contribute to more informed decision-making by players.

Furthermore, the issue of headgear design warrants special attention. Many players cited discomfort, bulkiness, and lack of ventilation as reasons for not using headgear. Enhancing the design to address these concerns, such as improving ventilation, achieving better fit, and reducing bulkiness, can make headgear more appealing and comfortable to wear. This can lead to a higher acceptance rate among players.

It is also worth considering whether making headgear compulsory under World Rugby rules could be a viable option. While this may face resistance due to individual preferences and potential challenges with enforcement, it could be explored further in the context of youth rugby, where safety is of utmost concern.

In conclusion, the diverse attitudes towards softshell headgear among youth rugby players highlight the need for a multifaceted approach to player safety. Addressing concerns related to comfort, ventilation, and information gaps, while exploring potential modifications to headgear design, can contribute to a safer playing environment for young athletes. Additional research is necessary to evaluate the actual impact of softshell headgear in reducing head injuries in youth rugby and to further inform policy decisions in the sport. Ultimately, the health and well-being of youth rugby players should remain a top priority, and efforts should be directed towards minimising the risk of head injuries and promoting a culture of safety in the sport.

RECOMMENDATIONS

Considering the findings from this study, several recommendations are proposed to promote player safety and well-being among youth rugby participants.

It is imperative to establish comprehensive education programmes and awareness campaigns, designed to reach youth rugby players, coaches, and parents/guardians, ensuring that all stakeholders are well-informed about the benefits and risks associated with softshell headgear. Educating players is pivotal in dispelling misconceptions and empowering them to make informed choices regarding headgear usage. Collaborative efforts with rugby governing bodies, schools, and youth rugby organisations should continue to emphasise the importance of headgear as a protective tool. Targeting both players and their parents or guardians is essential to ensure that decision-making is guided by accurate information.

Simultaneously, there is a need to explore design modifications that enhance the comfort, fit, and ventilation of softshell headgear. Ongoing research in this area, focused on materials and construction innovations, should aim to reduce bulkiness, improve fit, and prioritise player comfort. A critical aspect of headgear's effectiveness is proper fitting. The development and adoption of standardised fitting protocols should be encouraged. Standardised fitting procedures can enhance comfort and protective capabilities while addressing issues related to poorly fitting headgear.

Furthermore, the issue of affordability should not be overlooked. Initiatives to make headgear more financially accessible to youth players, such as subsidies, discounts, or sponsorships for youth rugby organisations, can help reduce financial barriers and encourage broader adoption of protective headgear.

The question of whether softshell headgear should be made compulsory under rugby regulations is one that deserves thorough exploration. While the idea of mandatory headgear usage may face resistance due to individual preferences and enforcement challenges, it should be considered in the context of youth rugby where safety is paramount. Such regulations would ensure a consistent level of protection for all players, thereby promoting a culture of safety.

In conjunction with these recommendations, longitudinal research is essential to assess the actual effectiveness of softshell headgear in reducing head injuries among youth rugby players. This research

© 2024 ARD Asociación Española

should consider variables such as age, level of play, and the specific types of head injuries encountered in rugby. Long-term studies can provide evidence-based insights for further safety measures.

Regular checks and maintenance of headgear should be promoted to keep equipment in optimal condition. Coaches and parents should be educated on how to assess headgear for wear and tear, highlighting the importance of well-maintained protective equipment.

Furthermore, the establishment of a feedback mechanism between players and manufacturers is necessary. This ongoing dialogue can inform future innovations, ensuring that headgear remains in line with the evolving preferences and needs of young rugby athletes.

Finally, a culture of safety should be promoted within youth rugby, emphasising the importance of prioritising well-being. Coaches, parents, and administrators should lead by example, emphasising the significance of protective equipment and adherence to safety guidelines.

These interconnected recommendations, ranging from education to design modifications, affordability, and cultural shifts, collectively address the multifaceted attitudes of youth rugby players towards softshell headgear. By implementing these measures, stakeholders in youth rugby can collaboratively enhance the safety and well-being of young athletes, creating a safer playing environment while allowing them to enjoy the sport with minimised potential harm.

AUTHOR CONTRIBUTIONS

Survey design was by Heward-Swale. Implementation of the research was by Heward-Swale, Spriggs and Henley. Heward-Swale performed the measurements, processed the experimental data and performed analysis. Kabaliuk conceptualised the study. Kabaliuk and Draper supervised the work. Hamlin supervised Spriggs. Heward-Swale wrote the manuscript. Kabaliuk and Draper reviewed and approved the final version of the manuscript.

SUPPORTING AGENCIES

Funding was provided by the Neurological Foundation and the Canterbury Medical Research Foundation.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICAL APPROVAL

This research received ethical approval from the University of Canterbury Human Research Ethics Committee (HEC 2021/26) and all procedures were conducted in accordance with relevant ethical standards and regulations.

INFORMED CONSENT

Written informed consent was obtained from all study participants and their parents, prior to the study.

ACKNOWLEDGEMENTS

We acknowledge the University of Canterbury for providing research scholarship for Heward-Swale, and the Neurological Foundation of New Zealand and the Canterbury Medical Research Foundation for research funding.

REFERENCES

Finch, C. F., McIntosh, A. S., & McCrory, P. (2001). What do under 15 year old schoolboy rugby union players think about protective headgear? Br J Sports Med, 35(2), 89. https://doi.org/10.1136/bjsm.35.2.89

Freitag, A., Kirkwood, G., Scharer, S., Ofori-Asenso, R., & Pollock, A. M. (2016). Systematic review of rugby injuries in children and adolescents under 21 years. Br J Sports Med, 50(8), 511. https://doi.org/10.1136/bjsports-2014-093684

Fuller, C. W., Taylor, A., Kemp, S. P. T., & Raftery, M. (2017). Rugby World Cup 2015: World Rugby injury surveillance study. Br J Sports Med, 51(1), 51-57. https://doi.org/10.1136/bjsports-2016-096275

King, D., Hume, P., Gissane, C., Brughelli, M., & Clark, T. (2016). The Influence of Head Impact Threshold for Reporting Data in Contact and Collision Sports: Systematic Review and Original Data Analysis. Sports Medicine, 46(2), 151-169. https://doi.org/10.1007/s40279-015-0423-7

King, D. A., Hume, P. A., Milburn, P., & Gianotti, S. (2009). Rugby league injuries in New Zealand: a review of 8 years of Accident Compensation Corporation injury entitlement claims and costs. Br J Sports Med, 43(8), 595-602. https://doi.org/10.1136/bjsm.2009.061481

Makovec Knight, J., Nguyen, J. V. K., Mitra, B., & Willmott, C. (2021). Soft-shell headgear, concussion and injury prevention in youth team collision sports: a systematic review. BMJ Open, 11(6), e044320. https://doi.org/10.1136/bmjopen-2020-044320

Menger, R., Menger, A., & Nanda, A. (2016). Rugby headgear and concussion prevention: misconceptions could increase aggressive play. Neurosurg Focus, 40(4), E12. https://doi.org/10.3171/2016.1.FOCUS15615

New Zealand Rugby. (2023). Get Involved. New Zealand Rugby. Retrieved from [Accessed March 04, 2024]: https://www.nzrugby.co.nz/get-involved/

Pettersen, J. A. (2002). Does rugby headgear prevent concussion? Attitudes of Canadian players and coaches. Br J Sports Med, 36(1), 19-22. https://doi.org/10.1136/bjsm.36.1.19

Pfister, T., Pfister, K., Hagel, B., Ghali, W. A., & Ronksley, P. E. (2016). The incidence of concussion in youth sports: a systematic review and meta-analysis. Br J Sports Med, 50(5), 292-297. https://doi.org/10.1136/bjsports-2015-094978

Quarrie, K., Gianotti, S., & Murphy, I. (2020). Injury Risk in New Zealand Rugby Union: A Nationwide Study of Injury Insurance Claims from 2005 to 2017. Sports Med, 50(2), 415-428. https://doi.org/10.1007/s40279-019-01176-9

Quarrie, K. L., Alsop, J. C., Waller, A. E., Bird, Y. N., Marshall, S. W., & Chalmers, D. J. (2001). The New Zealand rugby injury and performance project. VI. A prospective cohort study of risk factors for injury in rugby union football. Br J Sports Med, 35(3), 157. https://doi.org/10.1136/bjsm.35.3.157

Schneider, D. K., Grandhi, R. K., Bansal, P., Kuntz, G. E. t., Webster, K. E., Logan, K., Barber Foss, K. D., & Myer, G. D. (2017). Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies. Br J Sports Med, 51(20), 1473-1482. https://doi.org/10.1136/bjsports-2015-095645

Silver, D., Brown, N., & Gissane, C. (2018). Reported concussion incidence in youth community Rugby Union and parental assessment of post head injury cognitive recovery using the King-Devick test. J Neurol Sci, 388, 40-46. https://doi.org/10.1016/j.jns.2018.02.046

 © 2024 ARD Asociación Española

World Rugby. (2021). World Rugby Year in Review 2021. World Rugby. Retrieved from [Accessed March 04, 2024]: https://www.world.rugby/organisation/about-us/annual-reports

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Anthropometry and athletic performance with Zybek sports in elite American taekwondo athletes

Lynda Louise Laurin . *L3 Performance High-Performance Center. Our Lady of the Lake University. United States of America.*

ABSTRACT

Introduction: The relationship between anthropometric characteristics and athletic performance in taekwondo athletes is a topic of growing interest in the field of sports science and physical preparation. Objective: To determine the relationship between athletic performance in Zybek Sport tests and anthropometry in elite American taekwondo athletes. Methodology: A quantitative, descriptive, and correlational quasi-experimental cross-sectional study was conducted on a sample of (n = 470) taekwondo athletes. Anthropometric measurements included height, weight, and BMI. Athletic performance was assessed using Zybek Sports Performance Standardized Athletic Testing (SAT®). Results: Negative and statistically significant relationships were identified between the 10 and 20-yard sprints and height (p < .000) and (p < .000), weight (p < .000) and (p < .000), and BMI (p < .016) and (p < .000). The pro Agility test only showed a significant negative relationship with weight (p < .000) and height (p < .000). As for the 40-yard dash, horizontal jump, and vertical jump, which showed positive and significant relationships, it was identified that performance in these tests is influenced by greater height (p < .000), (p < .000), (p < .000), weight (p < .000), (p < .000), (p < .000), and BMI (p < .000), (p < .003) respectively. Except for the vertical jump, which did not show a significant correlation with BMI (p < .542). Conclusion: In conclusion, despite the heterogeneity of the relationships, lower weight, height, and BMI were found to improve performance in the 10 and 20-yard sprints as well as in the pro agility test. In the case of the 40-yard dash, horizontal jump, and vertical jump, greater weight, height, and BMI were related to better performance in these tests, with the exception of the vertical jump, which did not show a significant correlation with BMI.

Keywords: Performance analysis, Physical tests, Physical performance, Body composition, Taekwondo.

Cite this article as:
Laurin, L. L. (2024). Anthropometry and athletic performance with Zybek sports in elite American taekwondo athletes. *Scientific Journal of Sport and Performance*, *3*(2), 282-290. https://doi.org/10.55860/XQKJ6685

Corresponding author. *L3 Performance High-Performance Center. Our Lady of the Lake University. United States of America.*
E-mail: llltkd@gmail.com
Submitted for publication February 12, 2024.
Accepted for publication March 12, 2024.
Published March 14, 2024.
Scientific Journal of Sport and Performance. ISSN 2794-0586.
©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.
doi: https://doi.org/10.55860/XQKJ6685

INTRODUCTION

The relationship between anthropometric characteristics and athletic performance in taekwondo practitioners is a topic of growing interest in the field of sports science and physical preparation (Formalioni, A., Antunez, et al. 2020; Arazi et al. 2016; Wheeler, Nolan et al. 2012). Taekwondo, as a sport discipline, demands a unique combination of physical skills, including strength, speed, agility, balance, and flexibility, making it a highly specialized sport (Vargas, Vargas et al. 2010; Bridge, Ferreira et al. 2014; Pieter, 2009). Additionally, anthropometric characteristics, encompassing body composition, muscle mass, height, limb length, and other factors related to body structure, play a fundamental role in the performance of taekwondo athletes (Villalba, Morocho et al. 2018; Ojeda, Azocar et al. 2020).

Success in taekwondo relies on athletes' ability to execute kicks and defence techniques quickly and accurately, requiring a unique combination of muscular power and agility (Vargas, Vargas et al. 2010; Bridge, Ferreira et al. 2014; Pieter, 2009). Variability in anthropometric characteristics, such as the ratio of lean mass to body fat, can influence a taekwondo practitioner's ability to generate explosive force and move skilfully on the tatami (Villalba, Morocho et al. 2018; Ojeda, Azocar et al. 2020; Campos, Morine et al. 2009; Peña, Mieles et al. 2022). Limb length, in particular, plays a critical role in executing precise jumps and kicks, as well as in maintaining balance during competitions (Morine et al. 2009; Peña, Mieles et al. 2022).

The relationship between anthropometric characteristics and athletic performance in taekwondo athletes has garnered increasing scientific interest. Researchers and sports professionals have conducted numerous studies to better understand how these characteristics influence performance and how they can be used to optimize athlete training and assessment. These studies have highlighted the importance of designing specific training programs that take into account the individuality of taekwondo practitioners, considering their unique physical and anthropometric characteristics (Formalioni, A., Antunez, et al. 2020; Arazi et al. 2016; Wheeler, Nolan et al. 2012).

Similarly, it is crucial to conduct periodic measurements with reliable assessments to comprehensively track improvement in relevant variables. Various methods exist to identify these profiles through reliable and validated tests. In this context, we have utilized the Zybek Sport SAT test battery. It is important to note that, while this battery is not specifically designed for the taekwondo population, its reliability has been demonstrated in other disciplines, such as National Football League (NFL) American football, due to its movement patterns and evaluation conditions. Taekwondo, characterized by short and intense efforts with rapid and constant changes, finds a connection with the SAT battery tests. Although there are more specific tests to evaluate the physical abilities required in taekwondo, the SAT can be considered a reliable tool in this population. The discipline itself demands agile movements, efficient changes of direction, as well as leg power and explosiveness to execute techniques quickly and accurately. Specifically, speed and agility tests, such as the 10, 20, and 40-yard dashes, along with the Pro Agility 5-10-5, provide valuable insights into a taekwondo practitioner's ability to move quickly and change direction effectively. Vertical and horizontal jumps, on the other hand, measure the power and explosiveness of the legs, fundamental skills in taekwondo, where movements and techniques require a rapid extension of the lower limbs. Furthermore, speed tests, especially short-distance ones like the 10 and 20-yard dashes, assess anaerobic capacity, essential in sports involving intense and brief bursts of activity, as seen in taekwondo bouts (Laurin, 2021; Guillen, Shoemaker et al. 2019; Leutzinger et al. 2018). Given all the aforementioned, the objective of this study was to determine the relationship between athletic performance in Zybek Sport tests and anthropometry in elite American taekwondo practitioners.

METHODOLOGY

Design

A quantitative, descriptive, correlational, quasi-experimental, and cross-sectional study was conducted among a population of elite American taekwondo practitioners.

Population and sample

The study included 470 participants from various classifications, conveniently selected by researchers through a non-random sampling method. Inclusion requirements specified that participants had to be volunteers affiliated with USA Taekwondo (USAT) and have completed all phases of the study. Informed consent was obtained, and permission for participants under the age of majority was secured through relevant signatures.

Instruments, techniques, and procedures

Anthropometric measurements, including weight (kg), height (m), and Body Mass Index (BMI, kg/m²), were assessed as follows: Taekwondo athletes' weight was measured using a TANITA® BC-585F scale. Measurements were taken in the morning, while fasting, in loose clothing, and barefoot. Three measurements were taken per athlete, and the last one was selected for confirmation. For height, the ISAK standardized Zybek Sport stadiometer was used, with the athlete standing upright and barefoot. BMI was calculated using the formula Weight (kg) / (Height (m) * Height (m)) (Norton, 2018).

Athletic performance assessment utilized the Zybek Sports Performance Standardized Athletic Testing (SAT®) battery. Measurements were taken in the morning, and athletes underwent tests in the same order as anthropometric evaluations.

SAT® main tests included the 10, 20, and 40-yard sprints, the Pro Agility 5-10-5 test, vertical jump, and horizontal jump, measured in seconds and centimetres, respectively. Automated timing systems with digital laser beams provided by Zybek Sports (Fully Automated Timing Systems, Broomfield, CO) were used for the 40-yard sprint and Pro Agility tests. In the 40-yard sprint and Pro Agility tests, taekwondo athletes started from a three-point stance, similar to that used in track and field, with intervals recorded at 10 and 20 yards to assess acceleration throughout the test. It is noteworthy that the 10, 20, and 40-yard sprints measure straight-line speed, while agility tests evaluate the ability to perform bidirectional and multidirectional movements (Guillen, Shoemaker et al. 2019; Leutzinger et al. 2018).

Vertical jump height was measured as the difference between standing reach height and the maximum jump height using a standard testing device (Power Jump; Zybek Sports, Broomfield, CO), providing a measure of vertical power (Guillen, Shoemaker et al. 2019; Leutzinger et al. 2018).

Horizontal jump (BJ) was also measured in centimetres, determining the total distance from the starting line to the nearest part of the athlete's body at the time of landing, typically corresponding to the heel for most athletes. The best score achieved in each test was used as the representative score (Guillen, Shoemaker et al. 2019; Leutzinger et al. 2018).

Ethical considerations

Throughout this research, strict adherence to the guidelines set by the 1974 Protection of Human Subjects Act, also known as the Biomedical Research Act, was maintained. Respect for fundamental rights, as per the 2013 Declaration of Helsinki by the World Medical Association, was ensured.

© 2024 ARD Asociación Española

Detailed information about the research purpose, procedures involved, voluntary nature of participation, and complete confidentiality of personal data was provided to all participants. Informed consent, signed by each participant, was obtained to fully comply with these standards. The practice of assigning codes instead of using participants' names directly in the database was employed to maximize privacy.

Statistical analysis

For statistical analysis, all collected data were entered into an Excel spreadsheet and then transferred to the SPSS Version 25 statistical analysis program. Categorical variables were described in terms of percentages and frequencies. The Kolmogorov-Smirnov test was applied to assess whether continuous variables followed a normal distribution for samples larger than 50. Continuous variables with a normal distribution were expressed using mean and standard deviation (SD), while those not meeting this criterion were represented using median and interquartile range (IQR). The correlation coefficient was used to establish the relationship between anthropometric measures and performance variables, with a significance level set at $p < .0005$.

RESULTS

The group of taekwondo athletes from the USAT in the United States that was analysed showed diversity in terms of categories, comprising (n = 153) cadet athletes, (n = 149) junior athletes, and (n = 168) senior athletes. Regarding gender, (n = 265) males and (n = 205) females were included in the study. The average age of the athletes was 15.2 ± 3.75 years.

Table 1. Sociodemographic and anthropometric characteristics of the population.

Characteristics	N	%
Athletes' Gender		
Male	265	56.38
Female	205	43.62
Total	470	100
Athletes' Category		
Cadet	153	32.55
Junior	149	31.7
Senior	168	35.74
Total	470	100
	M	**SD**
Age of athletes	15.28	±3.75

**Note: M = mean; SD = standard deviation.*

According to the data presented in Table 2, it is evident that the majority of the key variables in this study exhibited a non-normal distribution, as their significance level was below .005. Therefore, the null hypothesis (H0) is rejected, and the alternative hypothesis (H1) is accepted. On the other hand, the variables: Height, 10-yard sprint, and pro agility, showed a normal distribution, leading to the acceptance of the null hypothesis (H0).

According to the findings presented in Table 3, it was identified that the median height was 65.00 inches (IQR 62.00 – 68.00) and a weight of 125.60 pounds ± 28.03, resulting in a body mass index (BMI) of 20.75 (lb/in²), falling within normal values according to the classification of this instrument. For the 10, 20, and 40-yard sprint tests, results were obtained as 1.88 (IQR 1.78-1.98), 3.21 ± 0.33, and 5.85 ± 0.65, respectively. The median time for the pro agility test was 5.20 (IQR 4.92 – 5.45). Finally, for the horizontal jump and vertical jump tests, measured in centimetres, mean values of 80.13 ± 12.10 and 21.97 ± 6.53 were obtained.

Table 2. Kolmogorov-Smirnov Test for fundamental variables.

Characteristics	N	Test Statistic	Significance
Height (in)	470	0.076	.011
Weight (lb)	470	0.048	.000
BMI (lb/in²)	470	0.085	.000
10-yard Sprint (s)	470	0.046	.021
20-yard Sprint (s)	470	0.073	.000
40-yard Sprint (s)	470	0.161	.000
Pro Agility (s)	470	0.021	.200
Horizontal Jump (in)	470	0.060	.000
Vertical Jump (in)	470	0.097	.000

Table 3. Measures of central tendency and dispersion of the fundamental variables.

Characteristics	N	M	SD	ME	IQR
Height (in)	470	64.86	±5.01	65.00	P25 = 62.00; P75 = 68.00
Weight (lb)	470	125.60	±28.03	123.00	P25 = 106.00; P75 = 142.00
BMI (lb/in²)	470	20.75	±3.58	20.37	P25 = 18.54; P75 = 22.45
10-yard Sprint (s)	470	1.89	±0.16	1.88	P25 = 1.78; P75 = 1.98
20-yard Sprint (s)	470	3.21	±0.33	3.24	P25 = 3.03; P75 = 3.42
40-yard Sprint (s)	470	5.85	±0.65	5.96	P25 = 5.53 P75 = 6.30
Pro Agility (s)	470	5.19	±0.37	5.20	P25 = 4.92; P75 = 5.45
Horizontal Jump (in)	470	80.13	±12.10	79.00	P25 = 72.00; P75 = 88.00
Vertical Jump (in)	470	21.97	±6.53	20.70	P25 = 17.2; P75 = 25.60

**Note: M = Mean; ME = median; SD = Standard Deviation; IQR = Interquartile Range; P25 = 25th percentile; P75 = 75th percentile.*

Table 4. Pearson correlation between the variables of interest.

Characteristics	Height (in)		Weight (lb)		BMI (lb/in²)	
	Spearman's Rho coefficient	*p*-value	Spearman's Rho coefficient	*p*-value	Spearman's Rho coefficient	*p*-value
10-yard Sprint (s)	-0.233	.000*	-0.224	.000*	-0.111	.016*
20-yard Sprint (s)	-0.332	.000*	-0.315	.000*	-0.187	.000*
40-yard Sprint (s)	0.580	.000*	0.692	.000*	0.516	.000*
Pro Agility (s)	-0.309	.000*	-0.222	.000*	-0.071	.126
Horizontal Jump (in)	0.454	.000*	0.355	.000*	0.137	.003*
Vertical Jump (in)	0.235	.000*	0.145	.000*	0.028	.542

According to the findings of the Spearman's Rho correlation coefficient expressed in Table 4, negative and statistically significant relationships can be identified between the 10 and 20-yard sprints with height ($p < .000$) and ($p < .000$), weight ($p < .000$) and ($p < .000$), and BMI ($p < .016$) and ($p < .000$) respectively. This suggests that lower height, weight, and BMI will increase performance in these tests, and vice versa. The pro agility test only showed a significant negative relationship with weight ($p < .000$) and height ($p < .000$). Regarding the 40-yard sprint, horizontal jump, and vertical jump, which showed positive and significant relationships, it was identified that performance in these tests is influenced by greater height ($p < .000$) ($p <$

© 2024 ARD Asociación Española

.000) ($p < .000$), weight ($p < .000$) ($p < .000$) ($p < .000$), and BMI ($p < .000$) ($p < .003$) respectively. Except for the vertical jump, which did not show a significant relationship with BMI ($p < .542$).

DISCUSSION

The aim of this study was to determine the relationship between anthropometric variables and performance in Zybek Sport tests (SAT). The results of this study revealed several significant findings. Firstly, it was found that the weight of athletes showed a negative relationship with performance in the 10 and 20-yard sprints, as well as the pro-agility test, with a *p*-value < .000. This indicates that, overall, heavier athletes tend to have lower performance in these speed tests. This negative relationship may be attributed to the influence of weight on athletes' acceleration and speed capabilities. Another significant finding was the negative relationship between the height of athletes and their performance in the same tests, with a *p*-value < .000. This suggests that taller athletes tend to have lower performance in the 10 and 20-yard sprints, as well as the pro-agility test. The explanation for this relationship could be related to biomechanics and stride strength, as height may influence running technique. (Borba, Ferreira, 2016; Toro, Siquier et al. 2021) Additionally, a negative relationship was observed between the Body Mass Index (BMI) of athletes and performance in Zybek Sport tests, with a *p*-value < .016. BMI combines height and weight, and this negative relationship could indicate that athletes with a higher BMI have less outstanding performance in these speed and agility tests. (Borba, Ferreira, 2016; Toro, Siquier et al. 2021).

On the other hand, the 40-yard sprint, horizontal jump, and vertical jump, which showed positive and significant relationships, identified that performance in these tests is influenced by greater height, weight, and BMI. Except for the vertical jump, which did not show a significant correlation with BMI. In contrast to the 10 and 20-yard sprints and Zybek Sport tests, which demonstrated negative relationships with anthropometric variables, the results revealed a different scenario in the case of the 40-yard sprint, horizontal jump, and vertical jump. In these cases, positive and significant relationships were found between performance in these tests and certain anthropometric variables. (Borba, Ferreira, 2016; Toro, Siquier et al. 2021; Benavides, Salazar et al. 2021; Junior, Ascanio et al. 2020).

Firstly, the 40-yard sprint showed a positive and significant relationship with height, weight, and BMI. This indicates that taller, heavier athletes with a higher BMI tend to perform better in this speed test. The explanation behind this relationship may be related to the need for greater strength and power to accelerate and maintain high speed over a longer distance. (Borba, Ferreira, 2016; Toro, Siquier et al. 2021).

The horizontal jump also revealed a positive and significant relationship with height, weight, and BMI. This means that athletes with greater height, weight, and BMI tend to have better performance in this test, which assesses power and horizontal jumping ability. The influence of these anthropometric variables may be related to the strength and ability to generate thrust in the jump. (Benavides, Salazar et al. 2021; Junior, Ascanio et al. 2020).

However, it is important to note that, in the case of the vertical jump, although a positive relationship was found with height and weight, no significant relationship was identified with BMI. This suggests that, unlike the other mentioned tests, BMI does not seem to significantly influence vertical jump performance. Vertical jump is based on explosive leg strength, and this selective relationship with anthropometric variables may be related to the technique and biomechanics of the test. (Benavides, Salazar et al. 2021; Junior, Ascanio et al. 2020).

In relation to the univariate analysis, it was identified that the results in the 40-yard sprint in our study show similarities to those obtained by Leutzinger, Gillen, and others in 2018, who evaluated American football players, as in this study, the mean for the 40 yards was 5.85 ± 0.65 for taekwondo athletes and approximately 5.78 ± 0.50 for ages closest to our sample. However, significant differences are observed in the Pro Agility, where participants in our study recorded a higher time (5.20 seconds) compared to players who spent between 4.50 and 4.84 seconds. Additionally, our vertical jump of 55.80 cm turned out to be lower than the range of 57.6 compared to 66.5 cm obtained by Leutzinger, Gillen et al. in 2018. Regarding the horizontal jump, our results of 203.5302 cm are lower compared to the range of 209 to 258 cm of the players evaluated by Leutzinger, Gillen et al. in 2019. These disparities in results can be explained by several reasons. Firstly, the athletes evaluated in our study differed in age, with taekwondo athletes being younger compared to participants in the previous study, and they also had a higher height, ranging between 173 and 184 cm, and a greater weight, ranging between 73 and 119 kg. It is worth noting that the athletes in the previous study were American football players, which could influence the differences in the evaluated tests. It is important to mention that there are few studies that evaluate these types of tests in taekwondo athletes, if any. (Leutzinger, Gillen et al. in 2018).

In another study conducted by Gillen, Shoemaker et al. in 2019, involving high school students associated with American football, similar results were obtained in the 10-yard sprint, with 1.9 ± 0.2 seconds, compared to taekwondo athletes in our study who recorded 1.88 seconds (IQR 1.78 - 1.98). Likewise, Gillen's study obtained 3.1 seconds in the 20-yard sprint, a similar result to our study, which was 3.21 seconds. However, in the 40-yard sprint, our results were higher, with a time of 5.8 seconds, compared to Gillen's 5.3 seconds, indicating that our participants took more time in this test. Also, our results in the Pro Agility were lower, indicating that our participants spent less time compared to Gillen's study in 2019. Additionally, our vertical jump and horizontal jump were lower than the values of Gillen and others in 2019, with 64 cm and 203 cm, respectively, in contrast to the 273 cm in their study. (Gillen, Shoemaker et al. in 2019).

Limitations

It is evident that this study adopts a novel approach, as there is limited literature that has used the Zybek Sports Performance Standardized Athletic Testing (SAT), especially in sports other than American football. However, this novelty could pose certain limitations in discussions due to the limited availability of literature on this test. On the other hand, one notable strength of this study lies in the use of a sizable sample. Few studies can access large sample sizes for their research. However, it is important to highlight that the sample population was conveniently selected by researchers, which could restrict the scope of the study's findings and limit the applicability of the methodology in future research.

For a comprehensive understanding of the relationship between anthropometric characteristics and athletic performance, it is necessary to conduct research that examines causality. This involves determining whether anthropometric aspects effectively enhance athletic performance or if other factors come into play. Furthermore, longitudinal studies are recommended, which, by following athletes throughout their competitive trajectories, can provide a more holistic insight into how the relationship between these two constructs develops.

CONCLUSIONS

In conclusion, statistically significant relationships were established between anthropometric characteristics and athletic performance in the Zybek Sport test. Firstly, the 10 and 20-yard sprint tests showed a negative correlation with height, weight, and BMI, suggesting that shorter stature, lower body weight, and lower BMI

© 2024 ARD Asociación Española

translate to better performance in these speed tests. This indicates that, overall, heavier athletes tend to have lower performance in these speed tests. This negative relationship could be explained by the influence of weight on athletes' acceleration and speed capabilities. Additionally, concerning height, taller athletes tend to achieve lower performance in the 10 and 20-yard sprints. This association could be related to biomechanics and running technique, as height may influence athletes' stride. Regarding the agility test, only a negative and significant correlation with height and weight was observed, aligning with the previously mentioned findings. Greater height and greater weight can also affect the biomechanics, speed, and acceleration of athletes. Lastly, concerning the 40-yard sprint, horizontal jump, and vertical jump, positive and significant correlations were found. It was identified that better performance in these tests is influenced by greater height, weight, and BMI, except for the vertical jump, which did not show a significant correlation with BMI. The explanation behind this relationship may be related to the need for greater strength and power to accelerate and maintain high speed over longer distances. Additionally, the influence of these anthropometric variables could be related to the strength and ability to generate thrust in the jump. All these findings suggest that anthropometric characteristics can influence biomechanically in performance variables in Zybek Sport.

SUPPORTING AGENCIES

No funding agencies were reported by the author.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author.

REFERENCES

Arazi, H., Hosseinzadeh, Z., & Izadi, M. (2016). Relationship between anthropometric, physiological and physical characteristics with success of female taekwondo athletes. Turkish Journal of Sport and Exercise, 18(2), 69-75. https://doi.org/10.15314/tjse.94871

Benavides-Roca, L., Salazar Orellana, C., & Díaz Coria, G. (2021). Relación entre las características antropométricas de masa muscular de extremidad inferior y la potencia de salto de jóvenes deportistas. MHSalud, 18(2), 134-150. https://doi.org/10.15359/mhs.18-2.9

Borba, DDA, Ferreira-Júnior, JB, Brant, VM, Guimarães, JB y Vieira, CA (2016). ¿Cuál es la contribución de las características antropométricas a la velocidad de carrera de corta distancia? Pensamiento práctico (Impr.) , 423-431. https://doi.org/10.5216/rpp.v19i2.40690

Bridge, C. A., Ferreira da Silva Santos, J., Chaabene, H., Pieter, W., & Franchini, E. (2014). Physical and physiological profiles of taekwondo athletes. Sports Medicine, 44, 713-733. https://doi.org/10.1007/s40279-014-0159-9

Campos, F. A., Morine, D., Avakian, P., Fernandes, C. A., Aoki, M. S., Moreira, A., ... & de Combate, M. (2009). Perfil antropométrico de atletas de taekwondo de alto rendimento. In Anais III Congresso de Ciência do Desporto. Campinas: FEF.

Declaración Helsinki, & World Medical Association. (1975). Declaracion de Helsinki. Principios éticos para las investigaciones médicas en seres humanos. Tokio-Japón: Asociación Médica Mundial.

Formalioni, A., Antunez, B. F., Vecchio, F. B. D., Cabistany, L. D., Coswig, V. S., Letieri, R. V., & Fukuda, D. H. (2020). Anthropometric characteristics and physical performance of taekwondo athletes. Revista Brasileira de Cineantropometria & Desempenho Humano, 22, e55697. https://doi.org/10.1590/1980-0037.2020v22e55697

Gillen, Z. M., Shoemaker, M. E., Mckay, B. D., & Cramer, J. T. (2019). State population influences athletic performance combine test scores in high school-aged American football players. International journal of exercise science, 12(6), 256.

Junior, N. K. M., Ascanio, W. J. A., Padilla, J., & Ortiz, P. (2020). Características antropométricas e do salto vertical de jovens karatecas. Edu-física. com, 12(25).

Laurin, L. L. (2021). The Relationship between Taekwondo Athletes' and Performance as Measured by SAT® Peak Performance, National Ranking, and Grit. Our Lady of the Lake University.

Leutzinger, T. J., Gillen, Z. M., Miramonti, A. M., McKay, B. D., Mendez, A. I., & Cramer, J. T. (2018). Anthropometric and athletic performance combine test results among positions within grade levels of high school-aged American football players. The Journal of Strength & Conditioning Research, 32(5), 1288-1296. https://doi.org/10.1519/JSC.0000000000002481

Norton, K. I. (2018). Standards for anthropometry assessment. Kinanthropometry and exercise physiology, 4, 68-137. https://doi.org/10.4324/9781315385662-4

Oficina para la Protección de Sujetos Humanos (OHRP). (1974). 45 CFR Parte 46: Política Federal para la Protección de Sujetos Humanos. Retrieved from [Accessed March 04, 2024]: https://www.hhs.gov/ohrp/regulations-and-policy/regulations/45-cfr-46/index.html

Ojeda-Aravena, A., Azocar-Gallardo, J., Galle, F., & García-García, J. M. (2020). Relación entre las características de la composición corporal y el rendimiento físico general y específico en competidores de taekwondo chilenos de nivel nacional de ambos sexos: un estudio observacional. Revista Española de Nutrición Humana y Dietética, 24(2), 154-164. https://doi.org/10.14306/renhyd.24.2.969

Peña-Sanchez, C., Mieles-Ramírez, M. R., & Patiño-Palma, B. E. (2022). Análisis del somatotipo en el taekwondo. Revisión de la literatura. Revista Investigación en Salud Universidad de Boyacá, 9(1), 95-114. https://doi.org/10.24267/23897325.763

Pieter, W. (2009). Taekwondo. Combat sports medicine, 263-286. https://doi.org/10.1007/978-1-84800-354-5_15

Toro-Román, V., Siquier-Coll, J., Bartolomé, I., Grijota, F. J., Maynar, M., & Muñoz, D. (2021). relaciones entre la composición corporal y las pruebas de velocidad, aceleración y cambios de dirección en estudiantes universitarios. Journal of Sport and Health Research, 13(1), 67-78.

Vargas, P. C., Vargas, G. A. A., & Gerardo, A. (2010). Perfil de rasgos psicológicos para el rendimiento deportivo en hombres y mujeres practicantes de taekwondo. Revista iberoamericana de psicología del ejercicio y el deporte, 5(2), 253-265.

Villalba, T. F. R., Morocho, L. E. S., & Frómeta, E. R. (2018). Indicadores antropométricos básicos para la detección de posibles talentos en el taekwondo ecuatoriano de ambos sexos. Lecturas: educación física y deportes, 23(242), 95-107.

Wheeler, K., Nolan, E., & Ball, N. (2012). Can anthropometric and physiological performance measures differentiate between Olympic selected and non-selected taekwondo athletes. International Journal of Sports Science and Engineering, 6(3), 175-183.

This work is licensed under a Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0).